EMERGING TECHNOLOGIES AND THEIR IMPACT
December 2005/January 2006
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MIT NEWS:
What It Means to Be an Institute Professor
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Technology Review

AN MIT ENTERPRISE

The Internet Is Broken

It's time to replace it.

BY DAVID TALBOT

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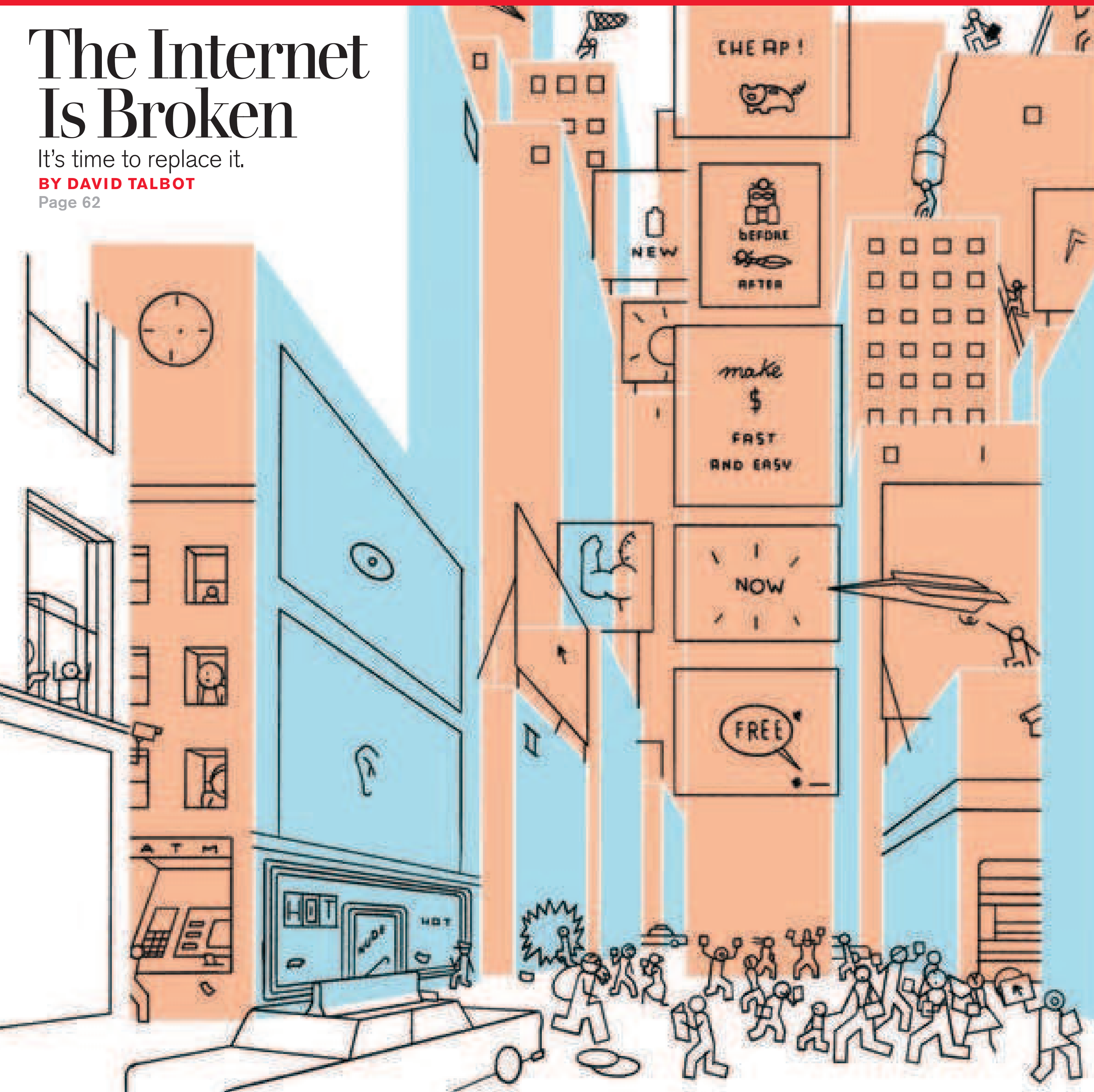

A Service Managing 7 Million Transactions a Day.
Running on Microsoft SQL Server 2005.

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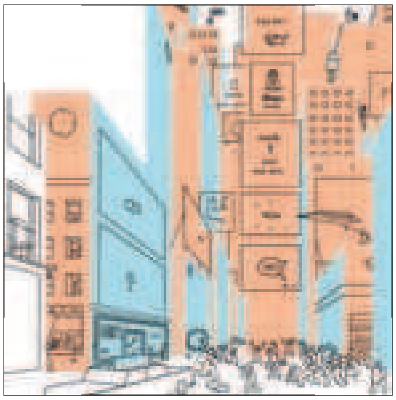

Cover illustration by Laurent Cilluffo


2005
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Technology Review

AN MIT ENTERPRISE

Technology Review
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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

Technology Review, the oldest technology magazine in the world, is published by Technology Review, Inc., an independent media company owned by the Massachusetts Institute of Technology. Founded in 1899, *Technology Review* describes emerging technologies and analyzes their commercial, economic, social, and political impact for an audience of senior executives, researchers, financiers, and policymakers, as well as for the MIT alumni. In addition, Technology Review, Inc. produces technologyreview.com, a website that offers daily news and opinion on emerging technologies. It also produces live events such as the Emerging Technologies Conference. The views expressed in *Technology Review* are not necessarily those of MIT.

MARK OSTOW

We're Changing

Technology Review and the future of publishing

This issue of *Technology Review* represents a departure. Oh, it looks much the same, I know. And save a few, largely cosmetic changes, it is the magazine you are accustomed to reading. As has been our custom since 1899, we describe emerging technologies and analyze their likely impact. Indeed, if readers find any alteration in our pages, they might note a stricter policing of that mission: we have eliminated coverage of technology business and financing because surveys suggested that you didn't want it.

But observant subscribers will have noticed that they did not receive an issue of *Technology Review* in November. More, anyone who visited technologyreview.com on November 4 saw an entirely new website. The events are related. We are becoming a very different kind of publisher.

The details are described for subscribers, advertisers, and the MIT alumni in letters attached to the December/January issue. (They can also be read online at www.technologyreview.com/dearsubscriber or dearadvertiser or dearalum.) In brief, we will print the magazine half as often, although existing subscribers will receive as many issues as they are owed. Our website will now post three news analysis stories a day, and also offer blogs, text-to-speech audiocasts, RSS feeds, and a variety of media like Flash. Content that is *only* available online will be free; premium content will be available to subscribers and the MIT alumni.

> The Internet has discomforted many industries, but traditional publishing is particularly unhappy. Readers are spending more time online.

Why these changes? Why mess with a good thing? In September, the board of Technology Review, Inc. asked me to take on the additional responsibilities of publisher. They encouraged me to consider innovative solutions to some of the difficulties of contemporary publishing.

The Internet has discomforted many industries, but traditional publishing is particularly unhappy. Readers (especially young readers) are spending more time online: increasingly, they want their information to be timely, searchable, personalized, and part of a social network. At the same time, advertisers are spending more money on interactive media: *they* are demanding efficiency, accountability, and a measurable return on their investments. The former's preferences would matter less were it not that the latter has sponsored the costs of print publication. Thus, at the very time when the costs of acquiring and retaining print readers are growing, when hiring the writers, editors, and designers has seldom been so expensive, publishers face the contraction of advertising revenues.

These trends have affected almost all publications except celebrity and fashion magazines. Even scholarly journals or publications like the *Economist* with relatively little advertising face an increasing demand from their readers for electronic publication. In short, the time when publishers could rely on print magazines is finished.

But the realignment of the publishing industry has hit *Technology Review* very hard. In part, this is because our technologically savvy readers and advertisers are unusually attracted to the Web; in part, it is because we are an independent company, unattached to any larger media company, and therefore unprotected by any economies of scale. Whatever the reason, our numbers told a stark story: our print circulation and advertising revenues were falling.

Online, though, was *something else*. Even though our website did little more than republish magazine stories, more people visited it every month than read our print publication: in one year, *millions* of people were reading stories on technologyreview.com. And online advertising, while still relatively small, was growing faster than we could manage: sometimes, advertisers demanded more impressions than we could deliver.

With the encouragement of MIT (which owns *Technology Review*), we have done what many publishers yearn to do, but dare not: we have turned our business upside down. *Technology Review* has been a print magazine with a website; from now on, we will be an electronic publisher that also prints a magazine.

To be clear: we love print. Most people still prefer to see longer, investigative stories or colorful photographs in a magazine. And we still receive more revenue from print than online advertising. So we will continue to publish a thoughtful and beautiful magazine. But we know the future of *Technology Review* is also electronic and interactive.

Please visit our new website and see what Brad King, the site's Web producer and senior editor, and Wade Roush, its editor, have made. If you read *Technology Review* because we write with unembarrassed geekiness and intelligence about emerging technologies, you'll find the same thing online every day. Once you've visited, write to me at jason.pontin@technologyreview.com and tell me what you think. **Jason Pontin**


with Intel® built in, Bumrungrad has
expansion built in

Digital Cartography

Your excellent cover story ("Killer Maps," October 2005) captured the developing landscape of competition between the likes of Google, Microsoft, and Yahoo over new location-based browsing, searching, and visualization. It's appropriate you began the article by describing the highly interactive nature of Google Earth and its 3-D interface for showing the earth. Although mapping applications like Microsoft's Virtual Earth and Yahoo Maps have APIs for customization, Google Earth uses a standardized XML-like interface allowing both simple and complex database enhancements, which tens of thousands of people have used to share many new innovative data sources, among them 3-D flight tracking, spread of avian flu, and collections of panorama images.

Frank Taylor
Raleigh, NC

Digital cartography, because it offers the ability to give title to land, may prove especially beneficial to the poor. The principal havens for illicit activities are, after all, poor nations, where criminals and terrorists frequently take land that is not theirs. Modern cartography technology could be used in places like Afghanistan, Colombia, and Peru to better see how land is being used. This would aid not only in helping to establish basic rule of law but also with efforts to move farmers away from cultivating narcotics, since new cultivations could be detected within days, if not hours.

Walton Cook
Boalsburgh, PA

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Please include your address, telephone number, and e-mail address. Letters may be edited for both clarity and length.

Food Fight

I read your editor's letter on *sous vide* and other new cooking techniques with interest ("Technology and Hypercuisine," October 2005). But I think Dry Creek Kitchen chef Michael Voltaggio is mistaken when he says, "But chefs and diners got bored....Now that people can buy restaurant-quality grills and ovens, anyone can braise veal cheeks. I want people to ask, 'How did he *do* that?'"

The question is really, *Why* did he do that? I have eaten at Chez Panisse on a regular basis since its opening 25 years ago and have yet to see the same menu twice. Its chefs have come and gone, but as Pontin says in his column, what has remained is founder Alice Waters's insistence on the use of "fresh, seasonal foods" that are "simply but perfectly prepared." I might stop at Voltaggio's restaurant one of these days, but I won't make a special trip, even though I often bicycle in that neighborhood. I will, however, be eating at Chez Panisse tonight, and I anticipate a wonderful dinner, one derived from an aesthetic of simplicity rather than one of complexity.

David Nasatir
Berkeley, CA

As the holder of a food handler's license in Multnomah County, OR, I can tell you that if an inspector from the state of Oregon came into a restaurant and found food being kept "hot" at 58 °C, he would cite the establishment for not maintaining a temperature of 60 °C or greater for hot food. Until the law is changed to reflect *sous vide*, I do not think the inspector would be swayed to approve that temperature.

Michael Kay
Multnomah County, OR

The End of Cheap Oil

Bryant Urstadt's review of James Howard Kunstler's *The Long Emergency* pits one man making a living from writing against another ("The Get-Ready Men," October 2005). Kunstler's popular tome offers the worst-case scenario of the world minus cheap oil, the production of which was long predicted to peak between 2000 and 2010 by the late geologist M. King Hubbert. But Urstadt's muddling-through scenario is hardly an adequate response. He himself admits that the bell-shaped curve of fossil fuel availability may well spell trouble, including social unrest of unprecedented proportions. The trouble may turn out to be serious, indeed. It may lead to a bell-shaped curve of human population, too. The flexibility and creativity of humanity, which Urstadt invokes in his review, may be of little solace to those at the tail end of that curve, let alone to those at its collapsing bulge.

Ranko Bon
Motovun, Croatia

The U.S. government has recently announced that it would use some or all of our strategic oil reserves to alleviate the shortages that have been brought upon us by Hurricane Katrina. I am writing to suggest that this should only be a first step in the managing of the strategic reserve.

What better time could there be than *now* to focus our long-range planning by taking advantage of existing technology and funding its improvement? Using a test portion of our 400-year supply of coal and/or the 600-year supply of shale, we could refill, say, 25 percent of the reserve by means of technologies created by Germany during World War II, and used by South Africa after the war.

While in the 1970s the cost of such a conversion process was not competitive with the price of crude (around $14 per barrel), the cost of a barrel has now reached $70. Cost discrepancy, therefore, should no longer be an issue, and thus immediate attention would be invaluable to our country for both the short and long term.

Gerard Mosseri Marlio
Marion, MA

Horace Freeland Judson says he approached his feature on science in China *(see "The Great Chinese Experiment," p. 52)* "as a skeptic, a doubter, ready to question all the current Western received opinions about China's economic miracle and scientific aspirations." Judson, the author of *The Eighth Day of Creation*, a history of molecular biology whose first three chapters appeared in the *New Yorker* in 1978, has two books in the works: one a collection of essays, the other a follow-up to *The Eighth Day*. Judson is, by his own accounting, "a writer by trade, an academic by accident." From 1965 to 1972, he filed arts and science stories from London and Paris for *Time*. More recently, he has held academic appointments at Johns Hopkins and Stanford, and he founded George Washington University's Center for History of Recent Science. Of his piece in this issue, Judson says, "Several of the interviews were among the best I've ever secured."

Paul Raeburn, a former senior editor at *BusinessWeek* and the Associated Press, was personally motivated to write this issue's story about advances in magnetic resonance imaging *(see "MRI: A Window on the Brain," p. 70)*. "I'm fascinated by the way researchers can take a technique like MRI scanning and extend it into new realms," he says. "As the parent of children who have suffered psychiatric illnesses, I know how difficult it is to get an accurate diagnosis. My kids went through a series of diagnoses before they were properly assessed and treated. And the same is true for many other parents and families." Raeburn is the author of *Acquainted with the Night*, a memoir about raising children with depression and bipolar disorder.

Laurent Cilluffo, who illustrated this month's cover, lives in northern France, where he recently completed the pilot for an animated TV show and a graphic novel that will be released in April. Cilluffo was not, at first, excited by our assignment: "I thought, Damn: another Internet piece." But he came around. "My main concern was to come up with the right color design, something that'd give a sense of depth, which I'd usually do with the line drawing itself. This time around it felt like I couldn't, or shouldn't, else the piece'd get overdetermined."

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6. Extent and nature of circulation:

	Average number of copies of each issue during preceding 12 months	Number of copies of single issue published nearest to filing date
A. Total number of copies:	346,774	304,608
B. Paid and/or requested circulation:		
1. Paid/requested outside-county mail subscriptions	261,274	249,449
2. Sales through dealers and carriers, street vendors, counter sales, and other non-USPS paid distribution:	44,015	15,175
C. Total paid and/or requested circulation:	305,289	264,624
D. Free distribution by mail:	2,391	576
E. Free distribution outside the mail:	4,776	3,763
F. Total free distribution:	7,167	4,339
G. Total distribution:	312,457	268,963
H. Copies not distributed:	34,317	35,645
I. Total:	346,774	304,608
J. Percent paid and/or requested circulation:	97.7%	98.4%

7. I certify that all information furnished on this form is true and complete:
(Signed) Heather Holmes, Director of Circulation

Debating Immortality

In February 2005, we published "Do You Want to Live Forever?," a cover story by physician and writer Sherwin Nuland that took a skeptical view of the claims of Aubrey de Grey, a theoretical biologist at the University of Cambridge who believes human aging can be "fixed." What follows is a letter to de Grey, care of our editor, from Richard Miller, a professor of pathology at the University of Michigan and a biogerontologist.

Dear Aubrey,

I saw you on TV the other day and was hoping that now that the aging problem has been solved, you might have time to help me in my publicity campaign to solve a similar engineering challenge: the problem of producing flying pigs.

A theoretical analysis of the problem shows that there are only seven reasons why pigs cannot, at present, fly:

1. They do not have wings.
2. They are too heavy to get off the ground.
3. The so-called "law" of gravity.
4. They cannot climb trees.
5. Hair, instead of feathers.
6. They do not wish to fly.
7. They do not tweet.

Although I have been too busy in my day job to find time to work in a laboratory, I have been able to show clearly that these problems can be solved, using an approach I call Plan for Engineered Porcine Aviation, or PEPA.

1. No wings: Genetic engineering will be used to alter Hox-box promoters and micro-RNA gene enhancers to reactivate the pre-wing somite program. A dab of stem cell therapy might help here, too.

2. Too heavy: Although the average pig cell is a chunky 20 microns in diameter, microbiologists have recently documented free-living organisms as small as .8 microns in diameter. By the inverse-cube law, a reduction in mean cell diameter of 25 will lead to a reduction in volume of $25^3 = 15,625$, with a corresponding drop in pig weight.

3. Gravity problem: This one's easy. Move the pig to Phobos, one of the low-gravity satellites of Mars, where people are going anyway.

4. Can't climb trees: Who says pigs cannot climb trees? Because so far most of their food has been placed in troughs or in the undergrowth of French forests, pigs have not previously been motivated to climb trees.

5. No feathers: The *Drosophila antennapedia* gene (for which a Nobel Prize was recently awarded) allows the transformation of bristles into legs or antennas.

6. Lack of motivation: Easy—LSD.

7. Tweet problem: Implantable helium sacs, just under the armpits, so whenever they flap their wings helium gets squirted into their vocal cavities.

Although each of these strategies is based upon sound scientific precedent or fantasy, nonetheless some of my conservative critics here on the local faculty have argued that no one has yet proven that any one of these methods has been shown to convert porkers to parakeets. But no one has yet tried all seven of them together, don't you see!

Amazing though it may seem, I believe that we are now at what I call a "cusp" in the history of either porkiculture or -aviation or both. Pigs born before April 14, 2009, will be destined to a life on the ground, rooting about for scraps, grunting unpleasantly, and constantly getting their curly little tails entangled in low-lying shrubs. Pigs born after April 15, 2009 (or perhaps a few days later), will in contrast waft lazily through the lambent skies, tweeting merry greetings to one another, nibbling at the occasional air truffle, and enjoying panoramic views of either Cambridge or Phobos, depending.

Aubrey de Grey declined our offer to print a short response. Find his full response at www.technologyreview.com/.biotech/wtr_15941,312,p1.html.

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Killer Maps
Net Compromise in Tunis
Both sides were able to walk away from last week's summit debate on Internet governance claiming victory.
The Lithium Economy
Why hydrogen might not power future vehicles and lithium-based batteries might.
Exercising the Brain
Innovative training software could turn back the clock on aging brains.
RSS Feeds
Newsletters
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More Blogs
More Stories
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From the Web Editor

Our Big Story

TR relaunches its website.

Telling the big stories about new technologies and how they will change our lives is what *Technology Review* has always done best. We don't get particularly excited about whether Google's stock price is $380 or $420, or how GlaxoSmithKline plans to market its latest pill. But we do care about Google's grand strategy to become the mediator of almost every type of online information exchange and are interested in how Glaxo and its competitors plan to invent the next generation of life-extending pharmaceuticals. Covering these big stories is what our bimonthly-magazine format—with its deep well of feature pages, longer lead times, and high-quality graphics and photography—is designed to support.

On the other hand, there's no law giving print magazines a monopoly on thoughtful technology writing. Faster-paced media such as the Internet may not be traditional outlets for *Technology Review*, but we do believe that Web publishing, in particular, can make our brand of technology coverage more timely, accessible, and interactive.

In November, we relaunched our website, www.technologyreview.com, with a new look and a new mission. Every weekday, we'll publish original articles by our own staff writers and our trusted freelancers. We will tell the bigger story behind the little stories—and hope to become your first stop every day for authoritative, provocative analysis of the key trends in information technology, biotechnology, nanotechnology, energy, space, and all the other technologies transforming our lives.

> We hope to become your first stop every day for authoritative, provocative analysis of the key trends in information technology, biotechnology, nanotechnology, energy, and all the other technologies transforming our lives.

Highlights from our first month of coverage on the website included two stories, by *TR* chief correspondent David Talbot and Kenneth Neil Cukier of the *Economist*, on the debate at the World Summit on the Information Society in Tunis, Tunisia, over U.S. domination of the Internet's name-and-address system. Talbot concluded that the ruckus was a dangerous distraction from more pressing problems, such as access, security, and censorship. Cukier described the story behind the summit's compromise solution: the new U.N. Internet Governance Forum, which will continue the international dialogue over domain names and other matters but will have no binding powers—allowing both the U.S. and its critics to leave Tunis claiming victory.

We aim to bring you similar insights into breaking technology news every day. Of course, the website will still be a place for subscribers to get the online version of the print magazine, and selected magazine stories will be offered free to all readers, often enhanced with interactive and multimedia elements. We've also revamped our discussion forums, making it much easier for readers to sustain conversations with us and with one another. I hope you'll stop by and let us know what you think. Write me at wade.roush@technologyreview.com. **Wade Roush**

What's new at technologyreview.com

We've developed an entirely new design and software infrastructure for the site. A few of our favorite features:

Enhanced Usability
We've focused on some basic principles. The time it takes to load a Web page should never exceed two seconds; readers should be able to resize their browser windows to fit their screens without losing view of the content; and all of our code should comply with the latest Web standards and meet accessibility guidelines.

Easier Navigation
The site now includes four simple tabs at the top of the page that link to our four main content "channels": Infotech, Biotech, Nanotech, and Biztech. Each channel's home page lists the most recent and most popular Web articles in its category. Other tabs will take you to the latest issue of *Technology Review*'s print magazine, our blogs, and MIT News.

Community-Building Features
We've replaced our old Forums with a new discussion interface that divides conversations about our articles into individual threads, so you can see who's responding to whom.

More Blogs
In addition to our longtime bloggers—*TR* editor in chief and publisher Jason Pontin, Web producer and senior editor Brad King, and Web editor Wade Roush—we've launched a new blog by editor David Rotman. Soon we'll also introduce a blog written by members of MIT's Comparative Media Studies program.

Canary Islands Wind Farm

Wind Power in Spain

Spain's installed wind-power capacity makes it the second-largest wind-energy producer in the world, and Spanish companies lead the global wind-power market. This is the first in an eight-part series highlighting new technologies in Spain and is produced by *Technology Review*'s custom-publishing division in partnership with the Trade Commission of Spain.

By Cynthia Graber

For governments and companies committed to the idea of powering our technological age with clean, renewable energy, wind power is a natural fit. Wind-powered technology has matured over the past two decades, driving down costs and driving up efficiency.

Today, countries like Denmark and Germany have demonstrated that integrating a power source such as wind into the grid can easily provide more than 20 percent—sometimes significantly more—of the power needs of a given region.

Now, Spain has joined them as a wind-energy powerhouse. With 9,000 megawatts of installed capacity, Spain ranked second in the world in 2005 in total installed capacity, behind Germany (16,000 megawatts) and ahead of the United States (6,500 megawatts).

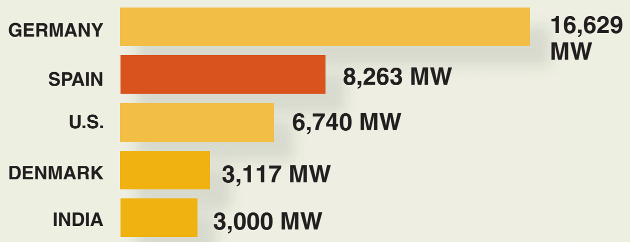
Furthermore, Spanish companies, both turbine manufacturers and wind-farm operators, are among the leaders in the global wind-power market. Some examples are Gamesa Eólica (world's second largest turbine manufacturer), Iberdrola (world's largest wind-farm owner and operator) and Acciona Energía (world's largest wind-farm builder and developer).

What's more, from the dense industrial base already present in Spain, many companies have sprung up to develop technologies befitting the needs of the wind industry, in fields such as composites, steel, electrical components, and wind-data loggers.

With 30 percent annual growth in the sector, and a clear commitment from the Spanish government to encourage private investment, technological advances, and grid development, Spain is poised to continue this trend toward powering its

Top Five Countries with Highest Total Installed Wind Capacity

The top five countries listed below account for over 67 percent of total wind energy installation worldwide.



Source: 2004 American Wind Energy Association

economic and technological growth with the strong winds that sweep over the country's mountains and plains.

Wind Power Is an Economic Winner in Spain

One reason Spain stands out from other European leaders in wind power, according to Corin Millais, head of the European Wind Energy Association, is that environmental issues have not been the major driving force behind this expansion.

"It's much more a story about regional growth, economic deployment, driving an economy that requires increasing amounts of energy," said Millais. "There's more of a fundamental value of wind power to an economy in Spain than in northern Europe."

And the figures in Spain support this claim. When the first renewable energy plan was enacted in the late 1990s, energy demand was predicted to increase by 1.2 percent per year. Instead, demand has grown by around 3 to 4 percent. In addition, wind power has grown much more rapidly than expected, with installed capacity increasing by about 30 percent per year. Currently, the government estimates that 300 to 400 Spanish companies are involved in wind power, supporting about 30,000 jobs, with that number expected to double by 2010. This healthy job growth experienced as well in other industries has been crucial: a decade ago, the unemployment rate in Spain was more than 20 percent; it has since fallen to 8.5 percent in 2005.

In addition to economic and technological development, wind power in Spain has transformed the countryside. All along northern Spain's famous Camino de Santiago (St. James' Way), an ancient Christian pilgrimage route through the Pyrenees, plains, and along the coastline, ending at the burial site of the martyr St. James in Santiago, pilgrims travel past modern-day windmills. But the transformation has been more than visual, for the income that wind farms bring to poorer rural areas has literally saved some communities.

The goals of the Spanish government in promoting wind are twofold. First, to reduce dependency on imported oil. "In relation to other countries in the OECD and the European Union, Spain is much more dependent on foreign oil," said Javier Garcia Breva, until fall 2005 director general of the Spanish Institute for Energy Diversification and Saving (IDAE), part of the Spanish government. "The country is very vulnerable to variations in the oil market. So, at the first analysis, the renewable energy plan has focused on increasing energy independence in Spain."

The second goal, according to Garcia, is equally important: reducing carbon dioxide emissions in line with the goals of the European Union. According to IDAE figures, if Spain meets its goal of generating 30 percent of its electricity needs from renewable power by 2010, with half of that amount coming from wind power, it will reduce emissions of carbon dioxide by 77 million tons.

A Global Trend

The rapid growth in wind-generated power in Spain reflects a global trend. According to the Global Wind Energy Council (GWEC), wind-power capacity has been increasing at least 20 percent each year between 2000 and 2005, and wind turbines today can produce 200 times more power than equivalent turbines two decades ago.

The wind-power sector is coming of age. Its energy is relatively cheap to produce, some of its technologies have matured—even though there are several breakthrough technologies being developed in Spain—and more countries and communities are turning to wind to reduce both their dependency on foreign fuel and their contribution to global warming. The GWEC expects the costs of power from wind to be competitive with those from conventional fuel within a decade.

In many areas, wind power is still more expensive than other conventional fuels, though costs have plummeted since the 1980s (when wind power was in its infancy). Today, according to the American Wind Energy Association (AWEA), in the windiest sites, wind power may sell for around 4 to 5 cents per kilowatt hour, which compares well with energy prices in new coal or gas-fired plants. Recent fluctuations in steel prices have kept wind power prices steady, rather than continuing this downward trend; but natural gas costs have risen in the same period, making wind increasingly attractive.

Today there are more than 50,000 megawatts of installed wind-power capacity around the world, up from only 17,000 megawatts a decade ago.

Surpassing Goals in Spain

The Spanish story reflects those dramatic changes. In 1999, the government set a goal for wind power at 9,000 megawatts of capacity by 2011. By midway through 2005, however, more than that amount of wind power had already fed into the Spanish grid, compared with only 800 megawatts in 1999–2000.

In response, in August 2005, the Spanish government once

Spain's Installed Wind Capacity by Region

Wind Power in Spain

Market Snapshot

- Total capacity by end of 2005* .... **9,500 MW**
- Total capacity target for 2011 .... **20,000 MW**
- Growth rate 2003–2004 .... **33%**
- Contribution to national power supply **6.5%**
- Peak contribution to Spanish electricity supply **24%**
- Equivalent number of households supplied .... **4 million+**
- Peak generation in 2004 .... **86,775 MW**

Economic Growth

Employment

- Total jobs in wind industry in 2004 .... **30,000**
- Jobs projected for 2011 .... **60,000**

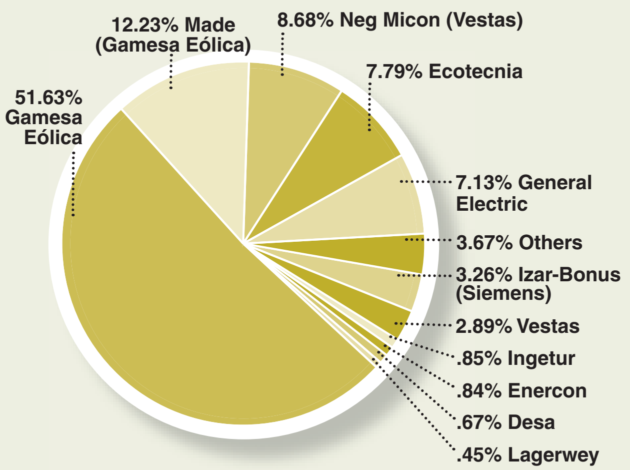
Top Growth Regions

- Castile La Mancha .... **731.5 MW**
- Castile and Leon .... **576.9 MW**
- Galicia .... **511.5 MW**
- Aragon .... **178.3 MW**

Source: AEE/IDAE/REE *Trade Commission of Spain

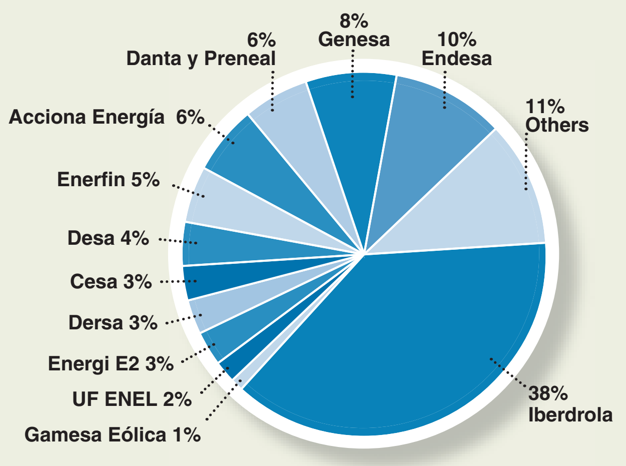
Spanish Market Share

Turbine Suppliers



Source: 2004 AEE

Wind-Farm Developers



Source: 2004 AEE

again reconsidered its goals. More ambitious numbers were needed to reflect the reality of the sector and to assure businesses that the government remained committed to this growth. As a result, a new goal of approximately 20,000 megawatts was set, a leap of almost 50 percent.

"I believe this is achievable for a very fundamental reason," said Garcia. "In Spain right now there is social and political consensus in favor of wind power. And that, together with the private-sector initiative, makes us very optimistic regarding the future of wind power."

Today, wind power fulfills about 6 percent of the country's electricity needs (in the United States, for instance, the AWEA's goal is to reach the 6 percent level by 2020). In Navarra, one of the autonomous regions that hosts a great deal of wind-power development, wind can fulfill nearly half of the region's power needs. "We're talking about a sector today that is one of the most dynamic parts of Spanish industry," said Garcia.

Creating and Developing the Wind-Power Market in Spain

Spain has created some of the world leaders in this industry. In the early 1980s, turbine manufacturer Ecotecnia was one of the first companies to install a wind-power generator in Spain. The company began in the renewable energies sector, then focused on wind generation when Director Antoni Martinez decided to follow the examples of Denmark and California.

According to Martinez, interest and business in wind-power began to pick up in 1992 and took off in 1997, when the Spanish government instituted a new electricity act. With the act, the government set a fixed premium every year according to the baseline cost of power from electric utilities, with a premium to ensure profitability for wind farms. In addition, utilities are obligated to buy any wind power produced and integrate it into the national grid.

Ecotecnia is still a major player in the Spanish wind-power market, selling turbines in Spain and around the world. What's more, the market has expanded to create international powerhouses like Gamesa Eólica, major national energy companies such as Iberdrola, and Acciona Energía, the renewable energies subsidiary of the Acciona Group, a major Spanish business group with thousands of employees.

Iberdrola set up its first wind farm in 2000; already by 2005, it had become the largest owner of wind farms in the world.

Meanwhile, Acciona Energía is the largest wind-park constructor and developer in the world. The company credits its success to its beginnings in the region of Navarra in 1994. "We were pioneers with a plan of implementing wind power in Navarra when wind wasn't yet looked on as an important economic sector," said the company's director of marketing, Jose Arrieta.

"This is giving real corporate credence to the industry. It's bringing in capital and financial sophistication," said Godfrey Chua, principal analyst of Emerging Energy Research, an independent organization that provides market research about wind power. "It's also bringing a level of scale to the industry that it has never seen before."

Most helpful in Spain, according to companies and the government, has been the stable environment created by government laws first passed in 1997 and updated as needed. The Spanish government sets the cost of wind power each year, based on the costs of power from conventional sources, with an added premium for wind to ensure a return on their investment.

Wind-power operators have two options: to sell electricity at a fixed rate that includes a tariff, or to sell freely in the market and receive a special premium on top of the market price. Each year, this premium is adjusted appropriately.

The Spanish Model

Similar to other pricing models in Europe, the Spanish model is different from the one pursued by the U.S. government. In the U.S., a national production tax credit provides a tax break for companies for 10 years after a wind farm is established. This production tax credit must be renewed in Congress —and often expires before it can be renewed. Thus, the market in the United States is subject to fluctuations, as developers and manufacturers, on renewal years, wait to see what Congress will decide.

This dynamic played out in 2004, when only about 400 megawatts came on line in the United States. The U.S. market has since picked up speed once again, and projected U.S. wind developments for 2006 are at about 2,500 megawatts. The tax credit is set to come up for renewal again at the end of 2007.

"The Spanish model guarantees the profitability of Spanish companies investing in wind power, and because of this, major companies in Spain have bet on wind power."

"The Spanish model guarantees the profitability of Spanish companies investing in wind power," said Garcia. "Because of this, major companies in Spain have bet on wind power. Those two factors together—the premiums and the investment from major companies—have contributed to what I would describe as the spectacular development of wind power."

Evolution of the Turbine

Over the past two decades, turbine manufacturers have experimented with different ways of transforming the energy from wind into power. Although models produced have ranged widely in size and shape, the one that has caught on and proved most effective and reliable is the three-bladed vertical model.

Improvements in design and efficiency have allowed manufacturers to construct larger, more powerful models, so that from a few hundred kilowatts of power years ago, turbines can now generate several megawatts.

"The fact that you have much taller wind turbines allows you to put the blades where the wind speeds are higher and more stable," explained Christine Real de Azua, a spokesperson for AWEA. "A larger blade means you have a larger swept area. These factors mean that, though the cost of a single turbine is higher, the output is so much greater."

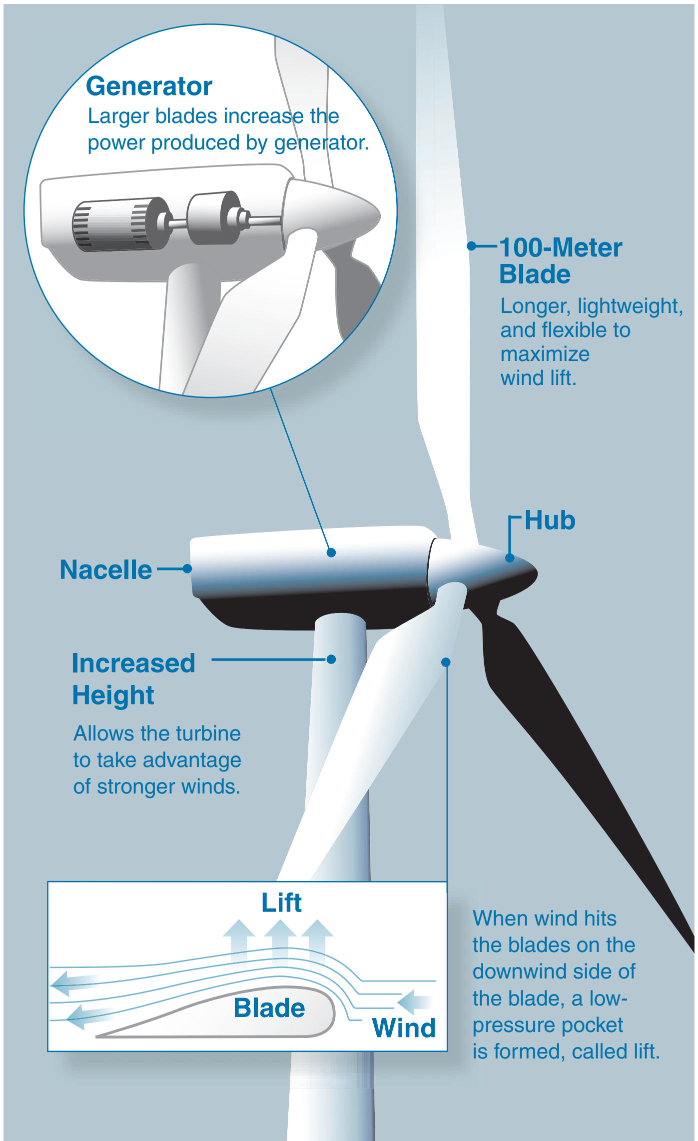
The standardized shape of wind turbines today, and the general trend towards larger and more powerful individual turbines, demonstrates the maturity of the technology, said Chua of Emerging Energy Research. It also means that individual companies distinguish themselves by incremental developments in technology that allow them to keep costs down, such as reducing the weight of the turbines and increasing their efficiency.

In Spain, Gamesa Eólica has grown to become the country's largest turbine manufacturer and the second largest in the world. Company sources say that a number of factors have led the company to take the lead. For one, they say, they have vertically integrated within Spain, designing the individual components and overseeing the manufacture of nearly all of them in the country.

To edge ahead of the competition, Gamesa Eólica has focused on pitch technology, in which blades can rotate by fractions of a degree to best take advantage of the wind speed, or to

Spanish Companies at the Top of the Global Market

Company	Specialty	Currently Operating in	Expansion Plan
Acciona Energía Largest wind-park constructors in the world www.acciona.es	• Wind-farm operation • Manufacturing of turbines • Developing wind-power facilities	Australia, Canada, France, Germany, Morocco, Spain, United States	China, Ireland, United Kingdom
Ecotecnia Second largest manufacturer in Spain www.ecotecnia.es	• Manufacturing turbines	Cuba, France, India, Japan, Portugal, Spain	China, Italy
Gamesa Eólica Second-largest turbine manufacturer in the world www.gamesa.es	• Manufacturing turbines • Wind-farm operation	China, Egypt, Germany, Ireland, Italy, Japan, Korea, Portugal, Spain, United States	Greece, Taiwan, United Kingdom
Iberdrola Largest wind-farm operator in the world www.iberdrola.com	• Wind-farm operation	Brazil, France, Greece, Italy, Mexico, Portugal, Spain, United Kingdom	Continuing to expand in Europe and Latin America



Innovative Turbines

Spanish companies are leading the way in turbine innovation by increasing the size of turbines while reducing turbine weight. The new longer (100-meter) blades can reach halfway down the length of the tower and help to maximize wind lift. Newer blades are also made of lighter, more flexible material, and in many turbines the blades shift angle, or pitch, either to catch more wind or to angle away in winds that are too strong. Spanish researchers are also developing new technologies to take advantage of wind changes and split-second power outages.

slow down to prevent a power overload. In addition, the company integrates variable speed into all turbines.

Gamesa Eólica believes that Spain's unique geography also provides a benefit to Spanish companies competing in the international market. As one Gamesa Eólica source put it, "Spain is a complex terrain, so our turbines have been reinforced to cope with that. Spain has many more mountains or hilly areas than central Europe, and this has helped us to design robust turbines that we can build anywhere in the world."

Although it is a much smaller company, Ecotecnia, Spain's second-largest turbine manufacturer, is highly competitive, focusing on reducing the weight of its turbines. They are currently developing a three-megawatt turbine with 100-meter blades, the largest of its line, that will be installed in early 2006. This giant turbine is designed for flat plains, where the increased height allows the turbine to take advantage of stronger winds. Like Gamesa Eólica, Ecotecnia is expanding around the Mediterranean region and into Asian and American markets.

Ecotecnia director Martinez says they're also researching new technologies that take advantage of minute changes in the wind and can cope with split-second outages in power. In the past, such dips in voltage, caused by brief failures in a traditional power plant or a disturbance such as a tree falling on a power line, would cause a wind turbine to disconnect from the grid.

Among the other manufacturers, MTorres stands out for its innovative technology. Its gearless and pitch-controlled windmills claim to increase performance and reliability, reducing maintenance costs. Furthermore, their offshore projects merge clean power resources with seawater desalination.

Challenges Ahead

Hurdles remain in the effort to make wind power even more successful in four main areas: variability, grid issues, centralized control center, and meteorological prediction.

Critics of wind power point to the inherent variability of the energy source as one of the main stumbling blocks to integrating it into the existing system. Yet the integration of wind in Spain has proven that variability is not such an impossible challenge.

"It's something of a red herring," said Real de Azua of AWEA. "No matter what new technology you bring on, a new nuclear plant or anything else, there's always the possibility that it's going to break down at some point, or be taken off the line for repairs and maintenance. No matter what, you have to have some margin of safety, of different types of plants that can meet the supply."

Godfrey Chua of Emerging Energy Research acknowledges that variability is a hurdle that wind power must overcome around the world. "The point is that wind power was never presented as the one power source, replacing all nuclear or coal. It's really meant to be complementary," said Chua.

In fact, while Spain has already reached 6 percent of energy

needs supplied by wind power, on certain windy days the sector can meet almost one-quarter of the country's power demand.

Former IDAE director general Garcia said: "The whole system has improved a great deal, including how it deals with peaks in the winter and the summer. In the peaks of the summer, wind energy has represented sometimes up to 15 to 16 percent of the energy distributed on the grid. And the stability of the system has improved a great deal as well."

Beyond the variability of the resource, grid issues remain. Traditional power sources are large power plants, sited relatively close to the demand. Current transmission lines reflect this reality. Wind turbines, however, may incorporate a number of smaller generators (an entire wind farm may have a few hundred megawatts of power, while a new nuclear plant may contribute a thousand megawatts). In addition, wind turbines may be farther from population centers (such as proposed wind farms in the midwestern United States) that necessitate upgrades and changes to the transmission lines.

While Spain has already reached 6 percent of energy needs supplied by wind power, on certain windy days the sector can meet almost one-quarter of the country's power demand.

In Spain, this issue has presented challenges as well. The Spanish grid has had problems absorbing the amount of wind power generated, according to Garcia. Upgrades to the transmission system are a top priority, according to the Spanish government, in reaching the stated goal of 20,000 megawatts by 2011. In particular, reinforcing and strengthening the power-sharing mechanism between Spain and France—and thus Spain and the rest of Europe—is of primary importance. When there is an energy need in France, Spain exports power to meet that need, and vice versa. But the transmission lines between the two countries are not yet adequately reinforced to support this two-way movement to its full capacity.

Because a great amount of wind power is generated in northern Spain, a stronger connection to France and the rest of Europe to better manage power surges and dips is paramount.

"It's similar to the situation of Denmark and Germany," said Garcia. "When wind is blowing in Denmark, they export it to Germany. And when wind doesn't blow in Denmark, Germany exports energy to Denmark. The European energy systems have to be interconnected."

Another challenge that needs to be addressed before the country can reach these ambitious goals, said Garcia, is creating a control center for all the wind farms around the nation, similar to the control center that exists for conventional power plants. Also, the technological challenges addressed by the turbine companies, such as technologies that deal with minute dips in voltage from the grid, will further the ability to meet the 20,000 megawatt goal.

Another factor that could increase efficiency is more-detailed prediction. Meteorological information allows electric companies and wind-farm operators to predict with a high level of accuracy when wind will pick up and slow down. With this hourly information, electric companies know when to expect more power from wind farms, and when to pick up the slack from other sources.

To reduce the inaccuracy in wind-power predictions, Spanish

wind farm operators are joining with system operators to determine the best practices for implementing improvements in predictions. According to Alberto Ceña, director of the Spanish Wind Energy Association (AEE), "Every day wind farms are offering power to the market. They need to reduce deviations—the difference between forecast and the real production."

Using seven different models, statistical and physical, the companies are refining prediction techniques. So far, in the first year since the project began, the accuracy has improved. "If we can reduce the deviation," said Ceña, "then we don't have to have conventional power plants on standby for producing power when we don't produce the power with wind. This also reduces penalties on the market."

With all these advances in place, Garcia believes that the goals of supplying 15 percent of Spain's energy needs via wind power and reducing the nation's dependence on fossil fuels by 2010 is achievable. "We wouldn't have proposed these goals if we didn't believe they could be met," he said.

Financial analysts are recognizing the strength of the Spanish industry. In the U.S., Ernst and Young in 2005 placed the Spanish wind market at the top of its index of long-term "country attractiveness."

Expanding Global Markets

According to the AEE, Spain has enough wind potential to meet 30,000 megawatts installed capacity—even without offshore wind farms, although a number of offshore projects are in the planning stage.

Of course no one expects wind power to replace all other forms of energy, but rather to be part of a diverse group of energy options. If Spanish wind-power developers and turbine manufacturers meet the government's goal of 20,000 megawatts by 2010, wind would supply around 15 percent of the country's energy needs. Even that figure is somewhat misleading, however, since natural fluctuations in wind mean that when wind is plentiful, it could supply half of Spain's needs.

Spanish companies are seeing steady demand and markets in Spain, and they look forward to supplying the power to meet the country's ambitious goals. At the same time, the rest of the world offers a much wider market for these companies, many of whom are already at the forefront of the industry. Gamesa Eólica, for instance, opened a wind farm in Illinois (Mendota Hills) in 2004 and recently opened its new North American office in Philadelphia. Today, it also sells its largest share of turbines in China, a market all companies are eyeing as that country's rapid industrialization demands more energy. Meanwhile, Iberdrola is already operating or plans to operate wind farms around Europe and Latin America, and Acciona Energía is working on an industrial project in China. Overall, Spanish wind-power companies are present in the United States, Portugal, France, Italy, India, Australia, Japan, Cuba, and China.

Financial analysts are also recognizing the strength of the Spanish industry. In the United States, Ernst and Young this year placed the Spanish wind market at the top of its index of long-term "country attractiveness," as assessed by their Renewable Energy Group.

Corin Millais, head of the European Wind Energy Association, says that Spain has not only influenced the current growth of wind power in neighboring countries—France, Portugal, and Italy, which have all increased wind-power targets—but Spain provides a model for countries around the world looking to implement stronger legislation and encourage the development of wind power. "Wind power is a dynamic market, and it is rapidly growing into a mainstream power," said Millais. "Spain shows how it can be done in a sustained fashion."

Resources

ICEX (Spanish Institute for Foreign Trade)
www.us.spainbusiness.com

AEE (Spanish Wind Energy Association)
www.aeeolica.org

AEH2 (Spanish Hydrogen Association)
www.aeh2.org

APPA (Association of Producers of Renewable Energies)
www.appa.es

APPICE (Spanish Fuel Cells Association)
www.appice.es

ASIF (Spanish Association of the Photovoltaics Industry)
www.asif.org (in Spanish only)

CIEMAT (Center for Research in Energy, the Environment, and Technology)
www.ciemat.es

IDAE (Institute for Energy Diversification and Savings)
www.idae.es

PSA (Almeria Solar Platform)
www.psa.es

To find out more about New Technologies in Spain, visit:
www.technologyreview.com/spain/wind

For more information visit:
www.us.spainbusiness.com

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SOFTWARE

Traffic Avoidance

New prediction service crunches road sensor data, weather, history, and local events

HENRIK SORENSEN/GETTY IMAGES

In the interminable battle against traffic, a growing number of government and private initiatives offer U.S. drivers high-quality real-time traffic data and even short-term predictions of travel time from, say, one freeway intersection to the next. But most of the forecasts don't extend beyond 15 or 20 minutes. Though a veritable traffic jam of companies has sprung up to offer data, they generally inform commuters of snarls as they occur, which is often too late for drivers to change their plans.

Now, actual traffic prediction—forecasts of congestion levels hours and even days in advance—is on the horizon. It's coming from Kirkland, WA–based Inrix, founded in 2004 by former Microsoft executives Bryan Mistele and Craig Chapman and former Expedia executive Seth Eisner. The company uses algorithms that originated in the labs of Microsoft Research; its technology is the first fruit of Microsoft's initiative to license intellectual property to venture capitalists and startups.

The Inrix software starts with a mass of data obtained from government agencies—real-time traffic flow and incident information from gadgets installed on highways, including toll-tag readers, cameras, radar units, and magnetic sensors embedded in the pavement. Inrix then adds speed and location data from computers and Global Positioning System (GPS) units in vehicles owned by trucking and delivery companies. These vehicles effectively act as mobile sensors, and Inrix buys the data they collect. Finally, Inrix adds up to two years of historical traffic flow data, weather forecasts and conditions, and even local road construction schedules,

school calendars, and dates of events like concerts and athletic contests.

The company's proprietary statistical models combine all this data to provide not only a snapshot of current traffic flow but also predictions about expected congestion and road conditions over the next several hours and even days. Each city requires its own unique model; the model for San Francisco alone contains about half a terabyte (500 gigabytes) of data, says Oliver Downs, Inrix's chief scientist.

Inrix plans to have models for the 30 largest U.S. cities available by the end of 2005 and to provide traffic predictions to drivers through partnerships of various kinds. It announced its first partnership, with digital-mapping company Tele Atlas, in September. Tele Atlas will offer Inrix services to all of its customers, which include companies such as MapQuest and T-Mobile Traffic. Inrix plans additional partnerships, with companies such as cell-phone operators, traditional and satellite broadcasters, and in-car navigation services.

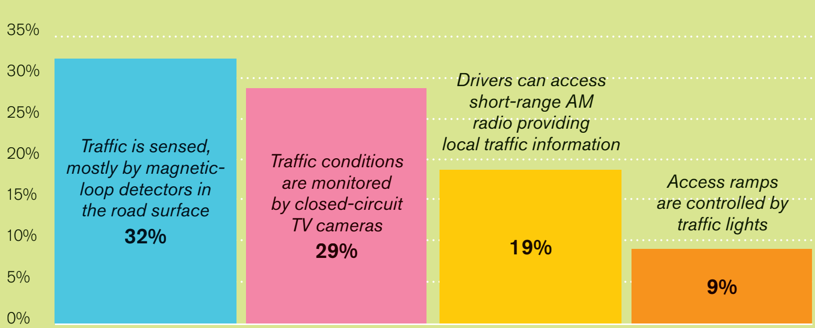
Approximately 3,000 drivers in the Seattle area have been using a prototype service based on Inrix's technology. Traffic information is delivered via smart phones, and sections of the city's highways show up as green, yellow, red, or black, depending on the level of congestion. The phones also display estimated times until roads will either clear or become jammed. The company says that the service correctly color-codes routes about 88 percent of the time when forecasting conditions up to 48 hours in advance.

The goal, says Mistele, is to provide drivers with truly useful information about traffic, such as the best route for a delivery van, the ideal time to leave work, how to reroute a trip to avoid an accident, or even an estimate of travel time from a New York City hotel to Newark Airport next Thursday evening. And while the cost to individual consumers will be set by resellers, current traffic services range in price from $20 to $120 a year.

Without doubt, there is a market for the kind of service Inrix has created, says Mark Dixon Bünger, who covers telematics as a principal analyst for Forrester Research. But predicting how well the company will do may be even trickier than predicting the traffic. "What is easy to say is that they've got great backing and they've got great finances. They're in a much better starting position—but it is a starting position—than most other companies." In fact, Inrix already received $6.1 million in first-round venture funding in April from August Capital and Venrock Associates. If Bünger's forecasts hold up, traffic prediction and dynamic routing will begin to make an impact in the marketplace within about five years. And if drivers have any luck, those predictions will mean they spend less time in gridlock. ERIKA JONIETZ

Tally of Traffic Technology

The 19,455 miles of freeways in the 108 largest U.S. metropolitan areas are being loaded with technologies for sensing and controlling traffic. Some of those technologies provide the foundation for traffic prediction services. The chart below shows the percentage of the freeways' lengths covered by a given technology.



Source: Federal Highway Administration

HARDWARE

Cooler on a Chip

As computer chips become faster and smaller, they also get hotter, and the fans used to cool PCs and keep their chips from slowing or failing can't keep up. To solve this problem, Thar Technologies in Pittsburgh, PA, has developed a microrefrigeration system that uses carbon dioxide to rapidly and effectively cool chips. Thar's key innovation is a microcompressor only 1.25 centimeters by 5 centimeters by 5 centimeters that compresses gaseous carbon dioxide into a "supercritical" state, where its properties hover between those of a liquid and a gas. The system cools the carbon dioxide through expansion and pipes it through an ultrathin heat exchanger. Just 125 micrometers thick, the exchanger sits directly on the microchip, drawing heat through the chip's packaging and cooling the electronics inside. This converts the carbon dioxide back into a gas; the gas is recirculated to the microcompressor, and the heat bleeds off by convection in a second heat exchanger. Lalit Chordia, Thar's founder and CEO, says the system can cool chips to lower temperatures than other technologies that use water or liquid metal; these lower temperatures translate into longer chip life. And the system is small enough to be used not only in desktop computers but also in laptops. Thar is now working to scale up manufacturing to produce the microrefrigerators reliably and cheaply enough for the computing industry. ERIKA JONIETZ

Forward

DESIGN

Refrigeration Unplugged

Almost two billion people live without a reliable source of electricity, but they may not have to live without refrigeration. In a simple, rugged twist on the gas-fired refrigerator, a prototype gadget uses heat from fire to create a cheap source of cooling. The cylindrical device, 10 centimeters in diameter and 20 centimeters long, has a chamber on each end—one made of steel and the other of aluminum. The chambers are separated by a ceramic insulator fitted with two valves. To charge the unit, a user places its steel side on a fire for 30 minutes. A liquid coolant in the steel chamber turns into gas and passes through a one-way valve into the aluminum chamber. After removing the device from the fire, the user lets it sit to allow the gas to condense, then inverts it and

Coolant chamber (left) is charged by heating, then placed in storage pot.

slides the aluminum end into a 38-liter ceramic food-storage pot. The coolant chills the food by absorbing heat and moving as a gas through the second valve—which opens when the device is inverted—back to the steel chamber. The device can keep food cooled to 4 °C for 24 hours. A prototype was demonstrated in 2005 by an industrial designer, William Crawford, at London's Royal College of Art. He says it could be built for as little as $18 per unit.

TRACY STAEDTER

BIOTECH

Ceasing Amniocentesis

Noninvasive test for fetal genetic defect reaches clinical studies

Pregnant women seeking prenatal tests for genetic defects face difficult choices. Either they accept less-than-reliable blood tests or ultrasound interpretations that leave them anxious and guessing, or they choose amniocentesis, which punctures the embryonic sac and has a small risk of causing miscarriage. Researchers have long envisioned the day when a test of the mother's blood or urine could conclusively detect a genetic defect in her baby. Xenomics, a New York City–based biotech firm, is now conducting the first clinical studies of a urine test that, it says, can detect Down syndrome in the fetus.

A pregnant woman's blood and urine both contain fragments of her fetus's DNA. Xenomics' advance is based on its discovery of specific DNA markers, called methylation sites, that may indicate whether a fetus has a chromosome abnormality related to Down syndrome. The Xenomics test under development uses standard DNA amplification technology to spot the markers in a urine sample. Xenomics is now conducting human clinical studies with two U.S. hospitals and hopes to submit the test for U.S. Food and Drug Administration approval in mid-2007.

The basic technique could work for certain other genetic disorders; ones that result from a mutation in a single gene are likely to have their own methylation markers, researchers say. Farideh Bischoff, a reproductive geneticist at Baylor College of Medicine in Houston, says scientists have identified the mutations that cause cystic fibrosis, Huntington's disease, beta-thalassemia, and other ailments. Although DNA tests for these diseases have been developed, says Bischoff, they require full strands of DNA found only in cells, not just the fragments that can be most easily found in maternal blood or urine. "Clinical trials using DNA fragments haven't been pursued to validate [them]," she says. But Bischoff predicts clinical trials will begin within five years and lead to new prenatal tests. "I think noninvasive testing is going to take over," she says. LAUREN GRAVITZ

COURTESY OF WILLIAM CRAWFORD (REFRIGERATION); JO TYLER

ROBOTS

A Helping Arm

Robotic physical therapy moves toward commercialization

Each year, two million Americans suffer brain injuries or strokes that can impair their ability to move their limbs. Traditional physical therapy can help patients compensate for the damage, but many patients tend to reach a plateau in performance after several weeks. Since the early 1990s, however, a few patients have been able to continue their progress thanks to an experimental robot built for arm rehabilitation. It never tires, adjusts as the patients improve, and precisely measures and monitors their performance. Now, that machine—plus three similar ones—are moving into large-scale tests equivalent to late-stage drug trials, the first such trials for therapeutic robots.

Run by the Veterans Health Administration, the new clinical study will involve approximately 200 patients. The randomized trials, set to begin next year and run for three years in an as-yet-undetermined number of hospitals, will test the robots head-to-head with traditional therapy. If all goes well, it "could provide the evidence needed to adopt the robot's clinical use throughout the VA system and possibly beyond," says Albert Lo, a Yale University neurologist and principal investigator in the trials.

The robots were built by MIT mechanical engineers Neville Hogan and Hermano Igo Krebs, who founded Interactive Motion Technologies of Cambridge, MA, to commercialize their work. The pair's first and most extensively tested device is a two-jointed motorized arm that glides parallel to a desktop. Patients grasp a handle and attempt to move it in and out, and left and right, giving their shoulders and elbows a workout.

Unlike physical-therapy treatments that simply move a patient's limbs repeatedly in a pattern, the arm robot enlists the patient's participation in the therapy, providing help only when needed.

The robot's software adjusts to the patient's progress. People starting out may not even be able to move their arms; at this stage, the robot fully impels and guides their movements. As patients improve, the robot gradually reduces the assistance it provides. At some stage, it may no longer help them move, instead only guiding movements along certain paths. Or it might wait before lending a hand, giving patients more of a chance to perform movements on their own.

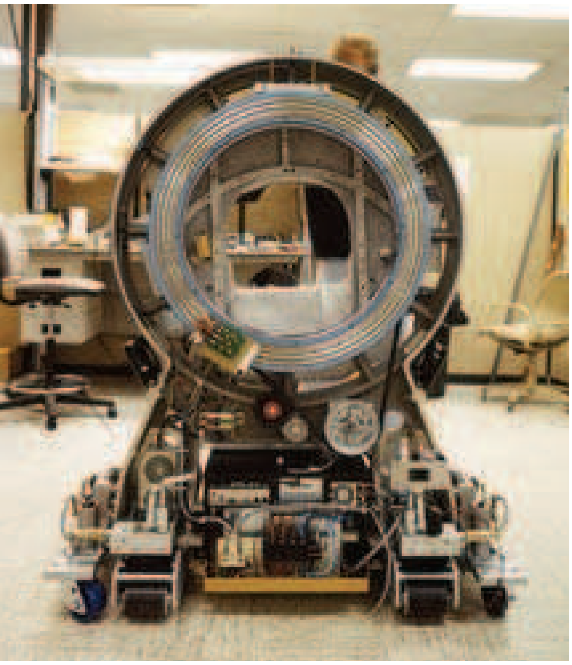
The device also has a video game component that directs the therapy and helps keep the patients motivated. The patients' movements guide a cursor on a computer screen toward targets. The computer regularly shows patients how well they are doing.

Stanley Schaffer, of Scarsdale, NY, who enjoyed playing classical piano until a stroke paralyzed one of his arms, says seeing his progress inspires him to keep trying. "You're competing against yourself," says Schaffer, who in a smaller-scale trial this year used the arm robot and a similar one for the wrist. With traditional therapy, he had stopped seeing improvements. But the robots have helped improve his mobility. "I feel that this is definitely going to help me get back to playing my piano with two hands," he says.

Interactive Motion's exercising robots are not alone. Companies working to commercialize therapeutic robots that focus on walking and balance include Chicago PT of Evanston, IL; Hocoma of Volketswil, Switzerland; Robomedica of Irvine, CA; and Yaskawa Electric of Tokyo, Japan. Taken together, corporate efforts and the latest clinical trials mean robots could eventually find widespread use in physical therapy. **KEVIN BULLIS**

A robotic arm assists stroke patients, who view a video game that helps direct physical therapy.

LEAH FASTEN



Clockwise from left: the CT scanner's compact power and control systems; company founders Bernard Gordon and Eric Bailey; one of the machine's scans.

MEDICINE

CT Scan to Go

First portable scanner for heads could fit in emergency rooms

The tremendous imaging power of computed tomography (CT) has helped transform medicine. But to date, CT scans have been beyond the reach of battlefield medics, ambulance crews, and even many emergency-room doctors. That's because conventional high-resolution CT scanners weigh almost 4,000 kilograms, require high-voltage power supplies for massive cooling systems, and must be installed in climate-controlled radiology suites. The lack of quick access is a particular problem in cases of brain trauma or stroke, when speedy treatment is critical.

NeuroLogica, a startup in Danvers, MA, believes its small, rugged, and portable machine will make CT scans more accessible. "Our primary emphasis was on getting a CT machine in an ambulance and emergency-room setting for heads only," says Bernard Gordon, the company cofounder, who estimates that 15 to 20 percent of CT scans are for the head and neck. "We need a machine they can afford all over the world that is rugged and can be worked by people with far less training than most radiologists." By 2005, a year and a half after NeuroLogica was founded, it had developed a machine suitable for emergency rooms and obtained U.S. Food and Drug Administration clearance for it; the company expects to deliver its first product this winter. It is now working on a version that could fit in ambulances.

The traditional CT scanner is a behemoth that looks like a giant point-and-shoot camera, with a hole in the middle instead of a lens. As a patient is conveyed through the hole, the machine continually shoots x-rays, and software combines the resulting images. After Gordon and two cofounders started NeuroLogica

ASIA KEPKA

in 2004, they set out to shrink the power supply and cooling system so they could use smaller x-ray-emitting tubes. In whole-body CT scanners, these tubes can be 30 centimeters in diameter and 50 centimeters long. NeuroLogica's engineers used tubes about 10 centimeters in diameter and 15 centimeters long. They created a power system about the size of a microwave oven, with a small fan to cool the tubes. The combined miniaturizations let them reduce the diameter of the donut-shaped machine to 44 centimeters, while the "donut hole" stayed at 32 centimeters, large enough for a human head. The machine delivers the same resolution as large machines, but the scanning speed is slower: a head scan can take up to two minutes, considerably longer than with a traditional machine.

The second problem was how to make the machine move when scanning a stationary patient. The solution was a novel set of tanklike tracks. "I needed an electrical guy to give me a motor and drive, and a robotics guy to make sure it could cantilever properly over rough surfaces, and a software guy to guide it through its steps," says Gordon. Finally, the device needed to be very rugged and simple to use. Whereas big scanners must operate at room temperature in order to preserve image quality, NeuroLogica's machine is designed for temperatures ranging from slightly less than 0 °C to 38 °C. It also includes a touch-screen interface that walks the operator through the scanning steps. All this in a 340-kilogram machine, light enough to be pushed by one technician and small enough to fit through a standard doorway. "Neurologists are dying for a machine like this, especially in ICUs [intensive-care units]," says Walter Koroshetz, a neurologist and head of stroke and neurointensive-care services at Massachusetts General Hospital in Boston. "We need to be able to scan these patients in the unit, not 10 flights away, dragging along nurses and doctors and wires and equipment."

Eric M. Bailey, another of the company's founders, says building the machine didn't involve developing new technology so much as essentially solving a complex packaging problem. It represents a leap beyond the previous best effort, heads-only CT scanners shrunk enough to fit into some ICUs but not portable or able to produce images that are up to today's standards. Says Bailey, "Frankly, it's just stupid people haven't thought of it sooner." **TOM MASHBERG**

SOFTWARE

Detecting Blood Loss

Patients who lose too much blood during surgery can suffer heart attacks. But measuring blood volume requires either inserting a catheter into the pulmonary artery, ordering an expensive echocardiogram, or resorting to guesswork. Kirk Shelley, an anesthesiologist at Yale University, has devised a way to noninvasively measure blood loss using a pulse oximeter, a finger-clip device commonly used to measure pulse rate and blood oxygen levels in hospital patients. The pulse oximeter measures how much light of different wavelengths the blood absorbs. After gathering pulse oximeter data from operating rooms for more than seven years, Shelley developed an algorithm that translates subtle absorption changes into accurate estimates of blood volume. Shelley says the algorithm can detect when blood loss exceeds one pint, information that can be used to guide transfusions. Shelley is negotiating with manufacturers that might license or buy the technology. If all goes well, the technology could reach operating rooms in 2006. KEVIN BULLIS

NANOTECH

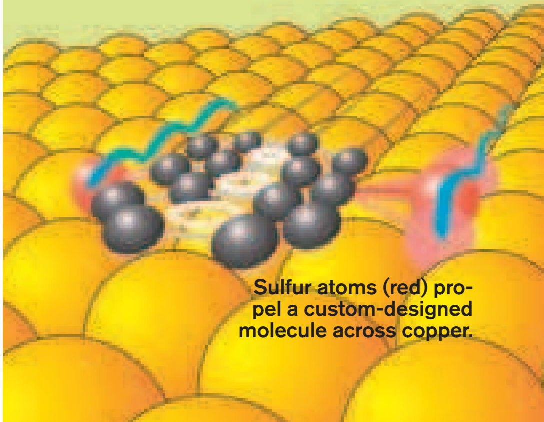
Wee Walker

Molecule moves in a straight line for nanomanufacture

If each bit of digital data could be represented by a single molecule, memory devices could shrink by more than three orders of magnitude. But manufacturing such devices requires a simple way to keep molecules straight and organized. A team led by University of California, Riverside, chemist Ludwig Bartels has come up with a possible solution: molecules that walk in a straight line, without guides or templates.

Called 9,10-dithioanthracene, or DTA, the new molecule sports two sulfur atoms protruding from a central structure made of linked benzene molecules. The Riverside researchers deposited DTA molecules on a smooth copper surface and cooled them to about -223 °C; they found that the molecules would then form rows and begin to move in straight lines—almost as if they were walking. "Effectively, [the molecule] kind of rotates around each of the feet and wobbles forward or wobbles backward," says Bartels. Biomolecules such as DNA and proteins have exhibited similar behaviors, but they've generally required some kind of molecular guide to align them. By contrast, all Bartels's molecule needs is a bit of heat.

The wobbly molecules won't show up in the next Dell computer, but Bartels believes that similar molecules could ultimately be useful in making molecular memory devices. "The work is amazing," says Rice University chemist James Tour, a leader in the field of molecular transport devices. The major challenge, he cautions, will be to tailor molecules to move in the same way on surfaces other than copper. **ERIKA JONIETZ**



Sulfur atoms (red) propel a custom-designed molecule across copper.

COURTESY OF LUDWIG BARTELS

HACKING

Game Boy Rock

In music clubs and dorm rooms around the world, intrepid geeks are transforming Nintendo's handheld Game Boy system into a do-it-yourself musical instrument. The device can be made to sequence its embedded sounds—digital blips and bleeps of the Donkey Kong sort—as if it were a synthesizer. First you find a programmable Game Boy flash memory cartridge and hook it up to your PC. Then you download a "chiptunes" music program, some of which are freely available, and transfer it to the cartridge. Once your Game Boy is loaded, you hit its controller buttons to arrange its signature sounds.

The results sound like computer game music of unusual complexity. Online, Game Boy musicians have posted their arrangements of songs ranging from "Let It Snow" to "Enjoy the Silence" by Depeche Mode.

Game hacking is nothing new. Enthusiasts of classic computers such as the Commodore 64 continue to churn out new uses for old systems. But chiptunes is the hot trend these days. In 2005, the alternative rock artist Beck embraced the medium, releasing Game Boy remixes of four of his songs.

Nintendo won't comment on the trend. But silence doesn't necessarily mean condemnation. "If it doesn't affect bottom line and [does] create interest in the platform in unique and novel ways," says Michael Gartenberg, a vice president at Jupiter-Research, "companies like Nintendo are comfortable with it." **DAVID KUSHNER**

NANOTECH

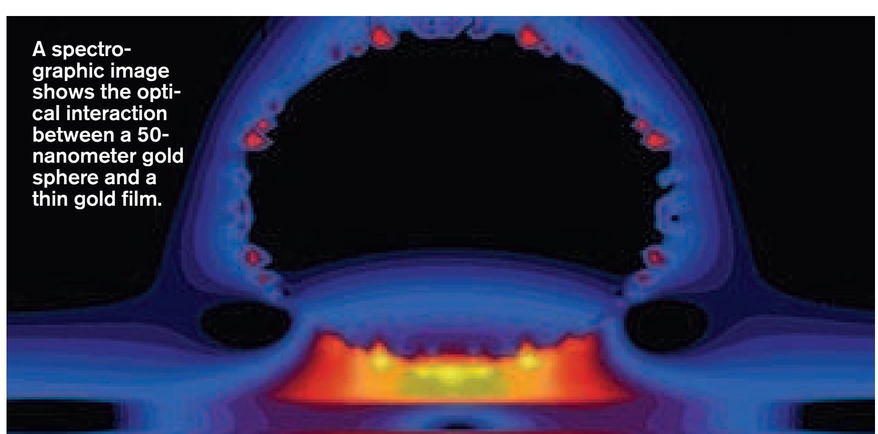
Nano Antenna

Gold nanospheres show path to all-optical computing

Vast amounts of data zip across the Internet each day in the form of light waves conveyed by optical fibers. But our computers still rely on electrical signals traveling through metal wires, which have much lower bandwidth. Optical interconnects that could guide light through the labyrinth of a circuit board would increase computing speed and save power, but so far they haven't made it out of the lab. New research, however, may enable engineers to build nanoscale antennae that turn light into a different sort of wave that can move through metal; the result could be data transmission speeds that are orders of magnitude higher than today's.

The key to the approach is a gold sphere just 50 nanometers in diameter. A Rice University team led by Peter Nordlander and Naomi Halas has shown that such a sphere, when positioned within a few nanometers of a thin gold film, will behave like a tiny antenna that can transmit or receive light. Light of specific wavelengths excites particles called plasmons inside the nanosphere. This in turn induces a "plasmon wave" in the gold film, which could be converted back into light when it reaches another nanosphere.

Variations on the gold nanosphere might make it possible to exploit materials already used in computer chips, such as copper and aluminum, as superfast optical interconnects, says Mark Brongersma, a materials scientist at Stanford University. A light wave encoding data would hit a metal nanosphere, generating a plasmon wave that would travel through a metal strip or wire, carrying the data with it. A huge benefit of the approach, Brongersma says, is how much easier the spheres are to make than other specialized antennae whose manufacture requires complex and expensive optical-lithography techniques. "The beautiful thing is you can make them in large quantities," Brongersma says. The Rice team's next step: using hollow gold "nanoshells" rather than solid spheres to expand the range of wavelengths of light they can use. And to further examine the practicality of using the systems as optical interconnects in computer chips, they have begun a series of experiments with nanoparticles and thin wires rather than thin films. **ERIKA JONIETZ**



A spectrographic image shows the optical interaction between a 50-nanometer gold sphere and a thin gold film.

ANDY POTTS; COURTESY OF RICE UNIVERSITY (NANO ANTENNA)

Philip Linden, Philip Rosedale's online avatar

Q&A

Virtual Economics

Philip Rosedale: founder and CEO, Linden Lab

More than 70,000 people participate in San Francisco–based Linden Lab's Second Life, the first online virtual community built around economics. The company's founder explains how a capitalist model fuels interest in a virtual world.

Q: How does Second Life's virtual world work?

A: Our residents create avatars. My Second Life avatar is "Philip Linden"—spiky hair, muscular tattooed arms, and sometimes a black T-shirt emblazoned with bright red Rolling Stones–style lips. Then they buy and sell land and use programming tools to develop it—homes, businesses, whatever you like.

What's the economic model?

If you want to own land, you pay a monthly fee of $9.95, which increases if you buy more land. But transactions aren't taxed. In 2003, we had a tax revolt. Our version of the Washington Monument was replaced by a giant tower of tea crates. We got the message: there are no taxes now. We're running about 1.4 million transactions a month, both goods and services—things like specialized programming.

And those transactions are in virtual money?

The currency is Linden dollars, which are convertible into real dollars if the players so choose, in an online market at prices they set. A recent exchange rate was 252 Linden dollars to one U.S. dollar. The GNP of Second Life in September 2005 was L$906,361,808 or U.S.$3,596,674, based on the recent L/U.S. exchange rate.

I see. People really buy into this?

The residents are creating a world which will be thousands of times more compelling than we could create ourselves. They also create and sell just about anything you can imagine—spectacular clothes, prefab houses, fun things like ray guns. Many of our residents already create scripts and objects that can be hacked and improved upon for everyone's benefit. On a server/architectural level, we do potentially see open source and peer-to-peer on the horizon.

Assuming a continuing supply of people with too much time on their hands, how big could it get?

Hardware and bandwidth would be big issues, but in theory, Second Life software could offer everyone on the Internet a 3-D presence. When we say Second Life is the next evolutionary step after the Web, we really mean it.

SPENCER REISS

SOFTWARE

Changeable Fingerprint

Your fingerprints are yours and yours alone, and that makes them a useful tool for confirming the identity of people doing things like conducting secure banking transactions or passing through corporate security checkpoints. Trouble is, it's theoretically possible for a hacker to break into the software of, say, an employer, steal a copy of your stored fingerprint, and later use it to gain entrance. So researchers at IBM have come up with "cancelable biometrics": if someone steals your fingerprint, you're just issued a new one, like a replacement credit card number. The IBM algorithm takes biometric data and runs it through one of an infinite number of "transform" programs. The features of a fingerprint, for example, might get squeezed or twisted. A bank could take a fingerprint scan when it enrolls a customer, run the print through the algorithm, and then use only the transformed biometric data for future verification. If that data is stolen, the bank simply cancels the transformed biometric and issues a new transformation. And since different transformations can be used in different contexts—one at a bank, one at an employer—cross-matching becomes nearly impossible, protecting the privacy of the user. Finally, the software makes sure that the original image can't be reconstituted from the transformed versions. IBM hopes to offer the software package as a commercial product within three years. DAVID TALBOT

A software transformation (bottom) differs subtly from the original fingerprint (top).

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Leonard Guarente

The skinny on the fountain of youth

Lenny Guarente has spent much of the last two decades patiently chipping away at the genetic and biochemical underpinnings of the aging process, an area of research often plagued by extreme hyperbole and extravagant claims. The MIT biologist is particularly focused on one tantalizing clue: for about 70 years, researchers have known that rats tend to live longer when fed a diet that is adequate in nutrition but very low in calories. While biologists are still unsure whether severe calorie restriction will have the same antiaging effect on humans, Guarente believes he and his fellow researchers have found the genes and a mechanism responsible for delaying the aging process—at least in lower organisms.

TR: If all goes well with antiaging research, what might be possible in five to 10 years?

Guarente: I hope in 10 years that we are way down the road of drug discovery in finding compounds that will deliver at least some of the benefits of calorie restriction. And I think SIR2 is going to be one of the important targets that we want to go after with drugs.

That's a gene you have identified as being involved in aging, isn't it?

We definitely think it is involved in the aging process. In particular, it seems to be involved in sensing caloric intake and asserting effects on cells to adjust life span. We think calorie restriction is a tremendous opportunity for us to intervene pharmacologically and have a positive impact on human health.

So people won't be going on a special diet to get the effects of calorie restriction, they'll take a drug?

I think so, because the amount of calories you would be taking in to get the benefits is rather a severe diet, about 1,000 to 1,200 calories a day. And most people who have tried this diet find it unpleasant. It makes them cold, it makes them hungry, they're irritable, and I think compliance would be very difficult. So, the idea is to understand what this diet does in an effort to develop drugs that would hit at least some of the targets and deliver at least some of the benefits.

You're talking about treating specific diseases, not the aging process.

The big idea here is that there is a close connection between aging itself and diseases of aging. If one had a favorable impact on the underlying aging process, diseases of aging would also be forestalled. And those diseases would include cancer, diabetes, cardiovascular disease, and neurodegenerative diseases—really major diseases.

How did you find this antiaging gene?

This gene came out of studies of aging in yeast. We started those studies in 1991, and the question we wanted to answer was, Do yeast cells age? And if they do, are there one or a small number of genes that are particularly important in dictating the life span of these cells? For four or five years we published nothing because we were just banging away at the problem. It took eight years before we could come to the conclusion that this one gene, SIR2, influenced the life span.

The gene also promotes longevity in worms and fruit flies. What seems to be its common role?

The idea would be that when food is scarce it is an advantage to be able to recognize the scarcity and slow down aging and reproduction, to postpone reproduction for when food becomes available again. And now there is some evidence that this is in fact the case.

Is this also true in humans?

It is a good hypothesis that something like this will be true in mammals. And there are hints. But I would say there is no conclusive evidence yet. But we know that the mammalian version of SIR2, which is a gene call SIRT1, has at least some of the activity in cells that one would anticipate for a life-extending function. What needs to be tested is whether it affects aging in the whole organism.

How large is this effect of calorie restriction on aging in rodents?

Studies show this diet could extend life up to 50 percent. So, it is pretty substantial. But there are people out there claiming science will allow people to live thousands of years. I tend to believe that is a lot of bunk. But the opportunity we do have is nothing to sneeze at. I think it is the major opportunity that Mother Nature has given us to intervene in the aging process. And by intervene I mean not just to promote longevity but to fight diseases.

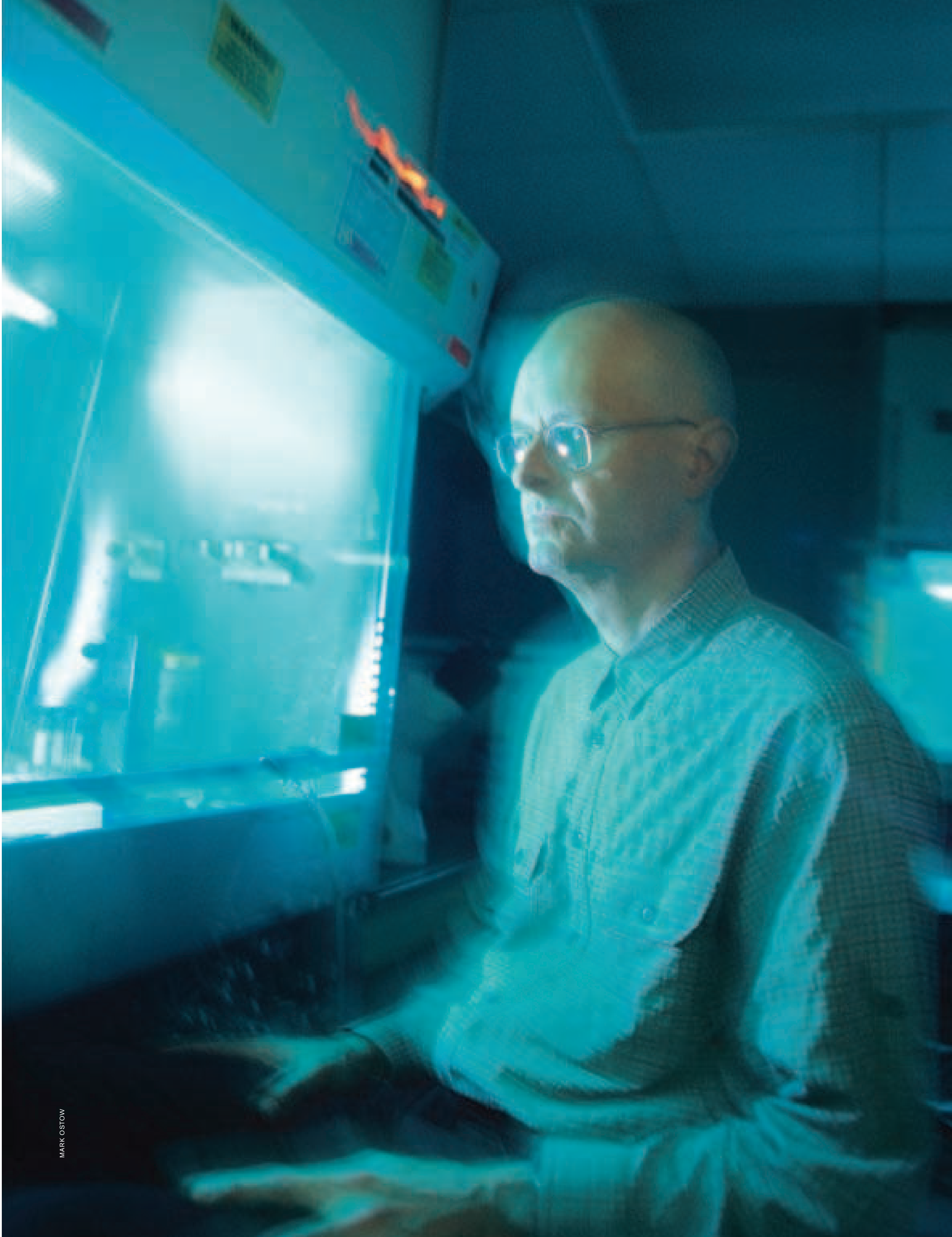
Other researchers are testing the antiaging effects of calorie restriction in monkeys, aren't they?

Those studies have been going on for some 15 years now. I know of two studies, and both are reporting that the diet induces the same physiological changes as in rodents, which is a very good indicator. There's no report yet on whether it makes the monkey live longer, because that data takes a long time to be available. But I think we'll know quite soon.

Is all the hype a good or bad thing for antiaging research?

It cuts both ways. The good part is where there is public interest, there is funding available for the research. The bad thing is that if the work does get overhyped in the media it raises false expectations. I get asked a lot, "What is taking so long?"

DAVID ROTMAN



MARK OSTOW

INFORMATION TECHNOLOGY

Newer Math?

Needed: a systems framework

By Rodney Brooks

While prognostications about "the end of science" might be premature, I think most of us expect that high-school mathematics, and even undergraduate math, will remain pretty much the same for all time. It seems math is just basic stuff that's true; there won't be anything new discovered that's simple enough to teach to us mortals.

But just maybe, this conventional wisdom is wrong. Perhaps sometime soon, a new mathematics will be developed that is so revolutionary and elegantly simple that it will appear in high-school curricula. Let's hope so, because the future of technology—and of understanding how the brain works—demands it.

My guess is that this new mathematics will be about the organization of systems. To be sure, over the last 50 years we've seen lots of attempts at "systems science" and "mathematics of systems." They all turned out to be rather more descriptive than predictive. I'm talking about a *useful* mathematics of systems.

Currently, many different forms of mathematics are used to model and understand complicated systems. Algebras can tell you how many solutions there might be to an equation. The algebra of group theory is crucial in understanding the complex crystal structures of matter. The calculus of derivatives and integrals lets you understand the relationships between continuous quantities and their rates of change. Such a calculus is essential to predicting, for example, how long a tank of water would take to drain when the rate of flow fluctuates with the amount of water still in the tank.

The list goes on: Boolean algebra is the core tool for analyzing digital circuits; statistics provides insight into the overall behavior of large groups that have local unpredictability; geometry helps explain abstract problems that can be mapped into spatial terms; lambda calculus and pi-calculus enable an understanding of formal computational systems.

Still, all these tools have provided only limited help when it comes to understanding complex biological systems such as the brain or even a single living cell. They are also inadequate to explaining how networks of hundreds of millions of computers work, or how and when artificial evolutionary techniques—applied to fields like software development—will succeed.

These are just a few examples of what are sometimes referred to as complex adaptive systems. They have many interacting parts that change in response to local inputs and as a result change the global behavior of the complete system. The relatively smooth operation of biological systems—and even our human-constructed Internet—is in some ways mysterious. Individual parts clearly do not have an understanding of how other individual parts are going to change their behavior. Nevertheless, the ensemble ends up working.

We need a new mathematics to help us explain and predict the behavior of these sorts of systems. In my own field, we want to understand the brain so we can build more intelligent robots. We have primitive models of what individual neurons do, but we get stuck using the tools of information theory in trying to understand the "information content" that is passed between neurons in the timing of voltage spikes. We try to impose a computer metaphor on a system that was not intelligently designed in that way but evolved from simpler systems.

My guess is that a new mathematics for complex adaptive systems will emerge, one that is perhaps no more difficult to understand than topology or group theory or differential calculus and that will let us answer essential questions about living cells, brains, and computer networks.

We haven't had any new household names in mathematics for a while, but whoever figures out the structure of this new mathematics will become an intellectual darling—and may actually succeed in designing a computer that comes close to mimicking the brain. TR

Rodney Brooks directs MIT's Computer Science and Artificial Intelligence Laboratory.

BIOTECHNOLOGY

Molecularly Driven

The way to a new detector

By Anita Goel

More than 10 years ago, as a physics undergraduate at Stanford University, I fell in love with the way the molecular motors known as polymerases read and write information from and into DNA. Experimental tools like optical tweezers were just emerging, making it possible to manipulate individual biomolecules. I joined the lab of Nobel laureate Steven Chu, who was pioneering biological applications of such technologies. In his lab, I became fascinated with the prospect of visualizing in real time the single-molecule dynamics of the polymerase motors.

I hypothesized that the dynamics of a molecular motor depend not only on the sequence of the DNA it is reading but also on the milieu in which it operates. Simply put, the environ-

ILLUSTRATIONS BY ELVIS SWIFT

ment changes the way cells process the information encoded within DNA. Perhaps cancer-causing mutations could be the result, in part, of environmental stresses on the motor as it reads DNA.

My quest to bridge physics and biomedicine brought me to a joint MD-PhD program at the Harvard-MIT Division of Health Sciences and Technology and the Harvard Department of Physics. I found an inspirational mentor in Nobel laureate Dudley Herschbach, a Harvard chemist. A significant part of my thesis was devoted to using concepts from physics and chemistry to theoretically elucidate how various changes in the molecular motor's environment could influence its actions along the DNA template.

Since my Stanford days, I had dreamed of harnessing these molecular motors for various nanotechnology and biotechnology applications, such as controlled synthesis, molecular manufacturing, and reading and writing information on the nanoscale. Then some folks in the U.S. Department of Defense invited me to brainstorm how emerging nanoscale technologies could be used to reduce the threat of biological terrorism. One evening, I had an epiphany about how to improve the accuracy and sensitivity of biosensors using nanoscale platforms. This led me to found Nanobiosym. With funding from the Defense Department, we have managed to establish the feasibility of nanoscale approaches to pathogen detection, which enables molecular diagnostic assays to be scaled down to the size of a chip.

Ultimately, we envision developing handheld pathogen detection devices to address not only the needs of the biodefense market but also those of the biomedical industry. Our approach compensates for some of the shortcomings of current sensors, enabling detection down to the single-molecule level. It is a personal interest of mine to make our technology available in the developing world, where the lack of infrastructure, such as electricity and running water, can preclude effective diagnostics. TR

Anita Goel, a physician and physicist, founded Nanobiosym in 2004.

NANOTECHNOLOGY

Material Alert

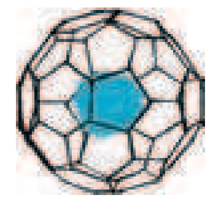
Smart clothes to aid soldiers

By Edwin L. Thomas

Soldiers have to be on top of what's going on around them; their lives depend on it. Technology helps: for example, night-vision goggles that amplify the ambient light either in the visible or near-infrared ranges. A great gadget, except for its weight, bulk, and need for batteries. Nanotechnology may provide some new great gadgets that are smaller, lighter, and more integrated.

What if you could integrate capabilities into soldiers' kits and clothing that would dramatically enhance their ability to monitor themselves and their surroundings? At MIT's Institute for Soldier Nanotechnologies (ISN), researchers are developing new materials that can sense changes in a soldier's body surface temperature and even tell whether he or she is being targeted by a laser.

Designing clothes that can "see and feel" is a goal of ISN materials scientist Yoel Fink and physicist John Joannopoulos, who are fabricating novel sensor fibers arranged from a semiconductor, metals, and insulators. The concept is to choose materials that become soft and highly deformable at a particular temperature. Fink and Joannopoulos chose the amorphous semiconductor arsenic selenide for the fiber core, with parallel contacting wires made out of tin, surrounded by the mechanically tough insulating polyethersulfone polymer. These materials are used to create a "preform" that is tens of centimeters long and a few centimeters in diameter. The preform is inserted into a specially built "draw tower," and a much smaller-diameter fiber is drawn out. It's tens of meters long but has a cross-section architecture identical to that of the preform.



The fibers can be designed to detect a specific color of light. The team incorporates a dielectric stack–reflecting layer into the fiber, a layer that is concentric with and surrounds the core semiconductor device. The reflector has a cavity in it that allows only light of a specific wavelength to pass through to the semiconductor core; that a fiber has been illuminated by a particular color of light is detected via a drop in the semiconductor's electrical resistance. Simply changing the thickness of the cavity in the reflecting layer makes the fiber sensitive to a different color of light.

The same approach works for temperature sensing, only the core semiconductor material is chosen so that temperature variations change its resistance, enabling body surface temperature to be monitored and mapped. A fabric that can see in color and feel heat and cold can be made through the cross-weaving of only a few thousand fibers. Inputs and outputs for power and control are still needed. But since the clothing has these fibers woven into it, it will provide 360 degrees of sensing in a package that is small and lightweight. TR

Edwin L. Thomas is Morris Cohen Professor of Materials Science and Engineering at MIT and directs the Institute for Soldier Nanotechnologies.

HEALTHY CELLS. HEALTHY AGING.

The Science of Aging.

Today scientists are attempting to challenge fate by investigating the secrets of aging. Dr. Bruce Ames, a renowned geneticist, leading biochemist and University Professor has been instrumental in researching the relationship between diet, maintaining healthy cells, and the aging process. His research links aging to tiny structures found inside cells called mitochondria.

Mitochondria are the powerhouses of our cells, producing most of our body's energy. Healthy mitochondria keep our cells healthy. Healthy cells provide energy, help keep the mind sharp, and provide a sense of overall well-being.

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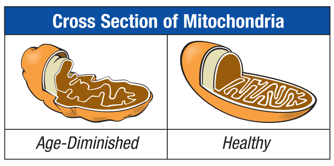

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LARA SOLT/DALLAS MORNING NEWS/CORBIS

Dirty Oil

As oil has become scarcer and more expensive, oil companies have begun seriously pursuing a politically charged method of oil extraction in Canada. The world's second-largest oil reserve lies under Alberta in the form of oil sand, which must be processed extensively to yield bitumen, a hydrocarbon mixture related to asphalt that can be turned into crude oil. It is estimated that 174 billion barrels of oil of varying quality could be recovered from the sands. Development is speeding ahead: so far, 34 billion Canadian dollars have been spent developing the oil sands, and another 45 billion in development projects will be completed by 2010 by companies including Petro-Canada, Syncrude, and Suncor.

Oil companies use large machinery and pipelines to transport the sand and rely on welling technologies to extend their reach to the bitumen buried far below the surface. With production at about one million barrels of oil per day in 2005 and expected to double by 2010, environmental groups worry that oil-sands development is speeding ahead too quickly. The following photos illustrate the process—and impact—of getting oil from sand. **Katherine Bourzac**

A grain of oil sand consists of a mostly quartz particle enveloped in a film of water, which is surrounded by bitumen, a thick, heavy oil. It takes roughly two metric tons of this sticky sand to produce one barrel of crude oil.

LEFT: GREG SMITH/CORBIS. TOP: COURTESY OF SUNCOR ENERGY INC. RIGHT: COURTESY OF PETRO-CANADA

Opposite and top: Where the oil sands lie close to the surface, mostly near the town of Fort McMurray in Alberta, they can be mined. In the effort to get at these sands, areas have been drained of wetlands and stripped of boreal forests, which play an important role in climate regulation and carbon storage. Their destruction contributes to the greenhouse effect.

Left: About 80 percent of Alberta's oil sand is too far below the surface to dig up. The most common method for getting the bitumen out is through two parallel horizontal wells lined with perforated pipe. Heat from high-temperature steam injected down one of the wells softens surrounding bitumen—which in oil sand form normally flows about as easily as Crisco—causing it to separate from the sand and flow down into the second well, from which it is pumped to the surface.

Above: Equipment used by oil-sand miners includes tractors with top-mounted radiators and cooling fans to protect their engines from oil particles and sludge, thousand-metric-ton shovels, and the Caterpillar 797. This colossal dump truck weighs more than 500 metric tons when empty. When its tires wear out after about a year, they are reused as cattle feeders.

Producing crude oil from the Alberta sands is an energy-intensive process. Giant digging and transportation machines use commensurately large amounts of fuel. Refining and welling technologies consume roughly 300 cubic meters of natural gas per barrel of recovered oil. Environmental watchdogs estimate that, as a result, producing a barrel of oil from the Alberta sands releases two to three times the volume of greenhouse gases that traditional oil production would. By 2015, production from the oil sands is projected to release 94 megatons of greenhouse gases.

Oil sand retrieved from surface mining is crushed and then moved to a processing plant via "hydrotransport." As the sand, mixed with water, tumbles through transport pipes, the

clumps of bitumen, sand, and water begin to loosen.

Above and right: The sand-and-water slurry is dumped into tanks with hot water, where it separates into three layers: sand, bitumen froth (impure bitumen), and a middle layer that is further treated to extract bitumen. Bitumen froth is also treated to remove impurities.

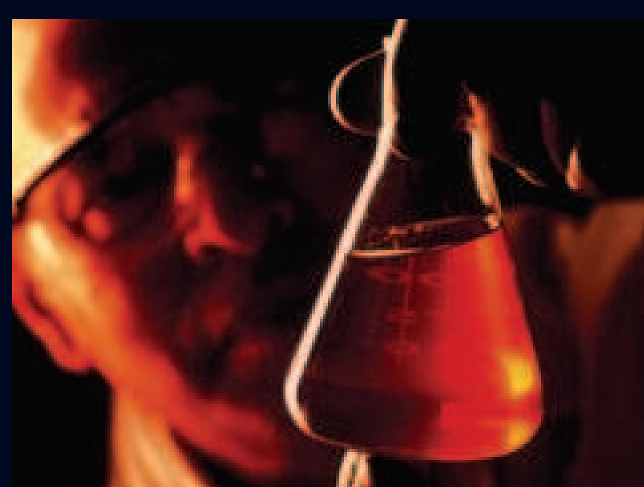
TOP: COURTESY OF SUNCOR ENERGY, INC. ABOVE: COURTESY OF SYNCRUDE CANADA LTD. LEFT: HANS-JUERGEN BURKARD/BILDERBERG

Left: Oil companies create ponds in which to dump millions of cubic meters of the sandy, toxic by-product of oil-sand processing. These “tailings ponds” are characterized by salt and acids. Here, a worker installs a scarecrow to keep birds away.

Right: Bitumen is a viscous mixture of long hydrocarbon chains—strings of as many as thousands of carbon atoms bonded to hydrogen atoms. These molecules must be “upgraded” to shorter molecules before they can be refined into petroleum products.

Purified bitumen is heated to break its long hydrocarbon chains into lighter molecules, such as naphtha, that can be refined. This process is called coking and takes place in large towers. The high-carbon by-product of the process, called coke, in turn fuels the coking furnaces. Distillation and a hydrogenation process are the final steps.

Below: The extensive processing of oil sand generates “sweet” crude oil, so called because of its low levels of sulfur and other impurities. Crude oil can be refined into gasoline of different grades and chemicals for making plastics.



LEFT: HANS-JUERGEN BURKARD/BILDERBERG. RIGHT: COURTESY OF SYNCRUDE CANADA LTD.

By Horace Freeland Judson
Illustrations by Brian Cronin

The Great Chinese Experiment

China is betting its economic health on becoming a world leader in the sciences. But will it succeed?

China is an economic catastrophe waiting to happen. China is poised to become the world's largest economy by 2025. Both these statements are true. They provide the context we must understand in order to evaluate rightly what the Chinese are attempting to do in the sciences.

When Deng Xiaoping came to power in the early 1980s, China was a Third World country, its vast population mired in poverty, trapped by massive economic failures and structural rigidities. Deng decreed that China must have the benefits of capitalist modes of investment and competition. He declared, also, that the foundation of economic and so of national greatness is science and technology. A quarter-century later, the dynamism of the Chinese economy is without precedent—steel, automobiles, toys, textiles, household appliances, on and on. Official statistics put the year-on-year growth of gross domestic product at 7.5 percent in 2001, 8.3 percent in 2002, 9.3 percent in 2003, 9.5 percent in 2004. Some Western economists think the real rates have been significantly higher. In any case, agreement is general that China's economy will soon outstrip that of the United States.

Yet its problems are on the same colossal scale. China has 1.3 billion people, predicted to peak at 1.4 billion in 2025—and 900 million are still rural and extremely poor. Corruption is widespread in provincial governments, in state-owned industries, within the Communist Party. The banking system is reported close to collapse. Social discontent is erupting: the government has admitted to tens of thousands of protests a year. Poverty is not confined to the countryside. In the main streets and glossy shopping malls of Beijing in summer, slim young women are stepping out in gauzy short dresses and frivolous shoes, but a block or two away are ancient alleyways—in Beijing called *hutong*—lined with low crumbling buildings, rows of minute cavelike shops open to the street with no lights lit, middle-aged and older men and women sitting idle, smoking, sullen on the stoops.

Pollution is pervasive, environmental degradation devastating. Smog in Beijing, Shanghai, and other cities reduces visibility most summer days to less than half a mile: when you drive along one of the elevated highways that cut through Shanghai, office and apartment towers emerge spectrally from the haze and then dissolve away. Seventy-five percent of China's lakes are said to be polluted; the lower reaches of major rivers run dry many days of the year. The problem most publicized is energy. China is already second only to the United States in energy use. Domestic oil or natural-gas supplies are negligible. China has abundant coal, of which it is the largest global consumer, mining and burning a quarter of the world's yearly output—at disastrous cost, some 6,000 miners killed underground in 2004 alone.

Even sophisticated and knowledgeable Westerners bring ideological preconceptions to their view of China. The most common is that economic growth requires laissez-faire capitalism, ideally on the Anglo-American model—and will inevitably lead to democratic reforms. But Chinese capitalism is not like, and will not necessarily approach, the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Western model. It is under state control—often erratic, to be sure, yet always threatening. The steel industry, the automotive industry, and the others were created from the top down. Goals are still set from on high, in five-year plans, and in detail. The men at the top are a new generation, intelligent, determined, relatively young. No question that they have learned from history—but not the lessons Western observers would like them to learn. Hu Jintao is paramount leader. He and his colleagues have attacked what they call "neoliberalism," specifically, laissez-faire policies. They admit no correlation between economic growth and any flowering of democracy. What had looked like a gradual relaxation of controls over press and television reporting has been reversed, sharply and increasingly.

All this is the barest sketch of the economic dynamism and the economic, environmental, and political constraints that shape Chinese science today. Following Deng, the Chinese government has been investing heavily to bring the sciences up to Western standards of quality, originality, and productivity. Roy Schwarz is a seasoned observer. Since 1997, he has been president of the China Medical Board of New York, which supports medical education and research in China. Schwarz has visited China four dozen times, for a total of a year and a half in-country. "In my cadre of 13 institutions, I support probably six out of the top eight medical schools," he said in a telephone interview. "Plus, I've funded probably, oh, 150 projects—some straight science, some are training programs for science, some are curriculum-related to science." The Chinese, he said, are doing everything they can to promote science. "I mean science across the board. From the space science that they've got going to the chemical and physical sciences, but especially biological sciences and medicine."

An early step was radical restructuring. Following the Soviet model, China in 1952 and in years following had set up a large number of separate single-specialty universities and schools. But in the summer of 1998, Jiang Zemin, then president of China, and Zhu Rongji, prime minister, brought representatives of prominent American universities to Beijing. The Chinese leaders learned that where their educational institutions were specialized, American universities are comprehensive. Their response, Schwarz said, was to adopt the American model. The result has been a large number of shotgun mergers. For example, the city of Hangzhou had four unidisciplinary universities, including one agricultural and one medical. In 1998, these were abruptly amalgamated into one, Zhejiang University. Zhejiang now has some 43,000 students, including 5,500 PhD candidates.

"Their universities have two structures of authority in them," Schwarz said. "The apparent one to Westerners is the president and the vice presidents and the deans. The one that's not apparent is the party secretary, vice secretaries—for every level on the academic side, you have one on the party side." Like the Red Army in the Soviet Union long ago? "Yeah, exactly right. And the latter is more powerful than the former—or it has been up to this point. But that's rapidly shifting." (Perhaps. But I noticed the all-but-universal practice that a Chinese scientist interviewed would have at least one other person present—a colleague, a student, someone supposedly to help with translation, often somebody involved with international relations. Nathan Sivin, the foremost living authority on the history of Chinese science, enlightened me in an e-mail message: "People from the foreign affairs office of a work unit are always handlers and reporters to the Public Security Bureau. In some organizations they are quite antsy, and in others supportive of the intellectuals they work with—so long as something does not threaten to draw trouble down on their own heads.")

Leading medical schools were already, like those in the United States, biological research institutes, although their work was largely unknown in the West. Now they were folded into universities. "In any other culture it couldn't have happened," Schwarz said. "But I think now the medical faculties are seeing the value of being part of a bigger whole. And I've watched the education of nonmedical presidents and party secretaries occur, as they try to understand this rare beast called a medical center." Reputedly the best of these is at Peking University, which in 2000 absorbed Beijing Medical University and renamed it the Peking University Health Science Center. Peking University's main campus is in a near suburb west of Beijing; the Health Science Center is several miles away. Such dispersal is an obvious consequence of the merger process. Zhejiang University has six campuses.

That dispersal may not last. Throughout the Chinese university system, modernization is intense. "They're all building these *gigantic* new campuses," Schwarz said. "I've visited five now." Unifying campuses, building new facilities, enforces integration. To head off faculty and administrative resistance to change, an extra $245 million was allocated to Peking University over the three years after the merger, according to Schwarz; the first of it was earmarked for the construction of world-class laboratories and acquisition of the best equipment. Laboratories I saw at nine different research institutions were high gloss.

The scope and areas of concentration of Chinese science have been laid down in greatest detail in a series of national directives. The most recent overarching directive is called the National Basic Research Program. Early in 1997, the Ministry of Science and Technology assembled an advisory committee of senior scientists and asked them what China had to do to achieve international competitiveness in the sciences while at the same time addressing its most acute domestic

problems. The committee presented its recommendations in March—hence the "97-3 Program" for short—and in June they were approved at the ministerial level and above. The language of the program's promotional materials can be Marxist-triumphalist: one English translation asserts that "we will create an excellent scientific research environment, intensively support a group of outstanding scientific research teams, conduct important innovation research, and scale the peak of the world's science, thus promoting the magnificent development of the China's basic research and the hi-tech industries." The details, though, are reasoned, practical, and in dead earnest.

Funding is, of course, the tool for directing and controlling science and scientists. To be sure, a number of Western corporations have set up facilities for technological research in China. Both IBM and Microsoft have laboratories in Beijing; Microsoft's is reputed to be the most consistently innovative in the corporation. The China Medical Board puts $10 million a year into medical education and research. In 2004, the Institut Pasteur, France's nongovernmental research institution, began working with the Chinese Academy of Sciences and the municipal government of Shanghai to set up and staff an institute whose research focuses on the molecular biology of infectious diseases. Two of the richest men in Hong Kong are giving money to certain specialized programs. These activities, though small in scale, have independence and visibility and so a degree of influence on the evolving culture of science in China. Otherwise, virtually all the money for science comes, through various conduits, from the government.

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Zhang Xianeng is director general for basic research at the Ministry of Science and Technology. We met during a break in an all-day governmental conference held at the Fragrant Mountain Hotel—an attractive, modern quasi-resort two hours out of Beijing on the lower slopes of the hills from which it gets its name. Zhang is a biochemist. He is lean, in his early 50s but looking ten years younger, a reflective man who speaks excellent English. "In China we have three major sources for research," Zhang said. Their aims differ. "One is from the National Natural Science Foundation of China. This foundation supports basic research driven by curiosity of the scientists themselves. The Ministry of Science and Technology is another funding source, supporting national-demand research," which is to say, research planned by the government to meet its urgent priorities. "We call this strategic research." He went on, "The ministry is a government agency. We not only support basic research. We also support applied research."

Throughout the system, distinguishing basic from applied is complex. "The Natural Science Foundation had a budget last year"—2004—"of about two billion yuan," Zhang said. At the then pegged rate of 8.28 yuan to the dollar, that was roughly a quarter-billion dollars. Comparisons are awkward, though, because the cost of research is so much lower in China than in the United States. "From our ministry," said Zhang, "10 billion"—U.S.$1.2 billion, or about a dollar per Chinese citizen. "But of the ministry's budget, about 10 percent goes to basic research. That's about half what the Natural Science Foundation gets."

The committee that recommended the 97-3 Program still functions to propose priorities for the ministry's approval. Even the "curiosity-driven" research supported by the Natural Science Foundation must fall within the categories of the program, conforming to the five-year plans of the research organizations. Architects of the program acknowledge, at least in principle, the need to let scientists shape their own research. In tension with that, though, they have devised a system of formal controls. Sixty-one "disciplinary evaluation panels" have been set up, with 753 experts. Institutions submit proposals by March 31. Each of these is vetted by one of the foundation's seven scientific departments, which range from mathematical and physical through chemical, life, and earth to engineering, information, and management sciences. Next step is peer review, done by correspondence and drawing on a pool of more than 20,000 reviewers; whether such reviewing is rigorous and free from bias must be in question (as is also true in the West). The results are analyzed and projects sent up to the evaluation panels, which submit surviving projects to an annual Natural Science Foundation meeting. Grants are for five years, and progress is reviewed after the first two—a system called "2+3"—to avoid the problem that once a project has won funding, the research team sits back and "the thinking becomes ossified," said Zhang.

"The third source of support, of course, is CAS, the Chinese Academy of Sciences," Zhang said. The nation's top scientists are academicians, and in that respect the Chinese academy is like the National Academy of Sciences in the United States or Britain's Royal Society; but it much more resembles the Max Planck Society in Germany, because it, too, directly runs a host

of institutes, the most important in centers such as Beijing or Shanghai, with others scattered across the country. These at one time numbered upwards of 130; but here, too, consolidations have been ordered. Many of those remaining have been shrunk through forced retirements, leaving more adequate support for those scientists who remain—and who can meet the pressure to raise additional funds outside. "CAS is bombarded for its institutes," Zhang said. "But they have very big freedom. Either curiosity-driven research"—about 40 percent of their budget—"or the strategic basic research."

One grave doubt had been on my mind since I first considered going to China, and the brute facts of the organization of the sciences there brought it to the fore. Is it possible to build a modern scientific establishment, doing important and original work to world standard, by ordering it from the top down, bringing it into being like a steel or automobile or electronics industry? Good science in our era is done in groups within groupings, from the individual laboratory to the research institution to the national network with its professional associations and controls and rewards, multiple levels of scientists judging scientists, to the world scientific community, integrated however loosely by shared attitudes and standards. New ideas, discoveries, grow from the bottom up. The culture of science, the ethos of science, must be rooted in the basic unit, the individual laboratory. From the laboratory's leader—called in China, as in the United States, the principal investigator, or PI—through senior colleagues down to postdocs, graduate students, and laboratory technicians, the group fosters and enforces the ethos of science. This is where the young scientist accepts the discipline, internalizes it, makes it a part of his or her personality. Or does not—for there are sick institutions in Western science, laboratories and larger institutions where the ethos falters.

The deep question for China, then, is how to plant and cultivate the discipline of science, the ethos. I raised this question with every scientist I talked to. Two problems demonstrate the difficulties—the Confucian problem and the plagiarism problem. These are not oddities or incidental aberrations. They are rooted, ingrained, internalized.

Howard Temin was an American molecular geneticist, who shared in a Nobel Prize in physiology or medicine for the discovery of the enzyme reverse transcriptase. He was a man of iron rectitude who had thought long about styles of doing science. In a conversation in March 1993, he told me, "One of the great strengths of American science...is that even the most senior professor, if challenged by the lowliest technician or graduate student, is required to treat them seriously and to consider their criticisms. It is one of the most fundamental aspects of science in America."

Behold the contrast. Harmony, consensus, respect for authority and for the views of elders: for thousands of years, this set of attitudes, Confucian for short (but a lot that was conventional before his time gets blamed on Confucius), has ruled the behavior of individual Chinese. At issue today is the power of a hierarchy based first on seniority and next on connections. Such a hierarchy is said still to govern much of the teaching of science in China; it lurks in laboratory relations. Most notoriously, it led to the misidentification in 2003 of the cause of the epidemic of severe acute respiratory syndrome, SARS. The first cases showed up in southern China late in 2002; the disease spread to Beijing and other cities and threatened to go global. In February 2003, a senior scientist in Beijing announced that he had found the cause, the bacterium Chlamydia. A junior in his laboratory knew that this was mistaken, for he had isolated the true cause. Out of respect, or fear, he said nothing.

This is an extreme but not an isolated example. I was warned of the problem repeatedly. Gerald Lazarus is dean emeritus of the medical school of the University of California, Davis, and now a professor at the Johns Hopkins medical school. His wife, Audrey Jakubowski, is a chemist. They lived in Beijing for three years, 1999 to 2001. He was a visiting professor at Peking Union Medical College and Hospital. For much of that time, she worked with an English-language scientific journal, the *Chinese Medical Journal*, trying to improve the English of the papers it published and to establish standards for review of manuscripts. Lazarus spoke of intellectual rigidities he encountered among faculty and students, caused, he thought, by deference to the views of elder colleagues. Jakubowski was more specific. The seniority system—she called it Confucian—could be crippling to peer review, she said, for to turn down a paper submitted by a senior person would be an act of disrespect.

The Chinese (and certain other Asian nations, of course) are notorious for pirating brand-name merchandise: copyright and trademark protection seem to have no meaning. Plagiarism is said to be flagrant in the sciences, too. American scientists and scholars who work with Chinese graduate students or postdoctoral fellows are surprised to learn they must teach new arrivals not to borrow others' work without acknowledgement—and the penalties for those who get caught. "The Chinese have a real problem with respect for intellectual property. They seem to have selective amnesia," Roy Schwarz said. Martha Hill, dean of Johns Hopkins's School of Nursing, said the same: "They come here, or many do, with no awareness at all of the necessity to give attribution, full attribution, for any material taken from others' work." Another division of Hopkins recently expelled a Chinese graduate student for plagiarism. Sivin noted that an exposé of plagiarism as a general problem published in China got its senior Chinese author into much trouble.

Yet Western preconceptions get in the way of understanding and effective response. Duplicating the latest Rolling Stones album, putting a counterfeit designer label on a pair of jeans—such acts are unembarrassed thievery. Plagiarism in the sciences is not like that. Classically, in the West, science is held to be communal: methods are shared, results once published are for the use of all. In that world, priority is the one form of ownership, making the need for attribution absolute. Unpublished data may be a target for theft, but a risky one. What's really worth stealing are ideas, above all the knowledge that *Ah ha*, here is something new and the way to get it. This kind of theft is the greatest temptation and the hardest to detect. It occurs; it can be prevented only by that strongly developed scientific culture, the sense of community—that psychologically internalized ethos of science.

The skeptic might suppose that what happens in China is no different from what one sees in many Western laboratories, where the boss appropriates and publishes under his or her name the work of subordinates. But the Chinese tradition is fundamentally different. Simply put, scholars at all levels have always been expected to incorporate the work of others into their own. In older times, principled scholars acknowledged their borrowings, but that remained optional (as in the pre-19th-century West). The attitude goes back many centuries; today it seems still strongly internalized.

In recent years, that classical Western ideal of the communality of science has been roiled, particularly in the biological sciences, by the lure of profits through patents. Many express outrage at the secrecy that preparing a patent application imposes and contempt for the excesses that have led, say, to the patenting of individual snippets of genomes. Rightly viewed, though, a patent is a form of publication and removes the need for secrecy, preserving priority yet restoring communality.

Here is a curious convergence. At some point in every conversation I had with scientists in China, I raised the problem of plagiarism. The response was always the same, and on first impression it seems unexpected—not evasive, exactly, but indirect. On reflection, it begins to look like acknowledging the problem, sure, but moving on to the ways, in the Chinese setting, that young scientists in the making might be brought to think differently, to see the benefits of taking in the Western norms. So institute directors and principal investigators say they teach that intellectual property means, in the first place, patents. Young Chinese scientists are urged to consider which of their results are patentable and to apply. Suddenly, out of the ruck of ideas, methods, data, discoveries that were loosely thought held in common, individual ownership emerges in a most hard-edged form.

Secondly, Chinese scientists are urged, commanded, to prepare their work and write it up to be published in top Western peer-reviewed journals. *Nature*, *Science*, *Cell* are targeted. Such publication is heavily emphasized in the 97-3 Program, and an individual laboratory's success in international journals is crucial at 2+3 time. National prestige is an important, overt motive here. The effect on individual laboratories and scientists, though, is to force them to absorb Western standards of quality, to live them, to learn to live by them. It is, in short, a process of acculturation.

In the decades since Deng Xiaoping declared science and technology to be of crucial importance, thousands of Chinese trained in the sciences have gone abroad as graduate students or, more usually, as postdocs. Most have gone to the United States, some to Europe. Many have stayed on, taking research jobs; some have returned. To China, they represent an immense and invaluable resource—for their particular skills and specialties but even more for their Westernized attitudes, their absorption of the ethos of modern science. The Chinese government has recognized their potential and is urgently trying to induce more to return.

Here are three Chinese scientists. Each of them did postdoctoral work abroad, then returned. Each is at the middle level of the profession, leading a laboratory, working intensively with a relatively small group. They are representative of others I met as well.

In Changsha, capital of Hunan province, in south-central China, where the summers and the food are blazing, the Central South University was formed in 2000 by merger of a university of technology, a medical university, and, of all things, the Changsha Railway University. The medical component is now the Xiangya School of Medicine. Cao Ya (her family name is pronounced *Tsow*) is deputy dean and director of the medical school. She has an MD and a PhD and spent five years in the United States at the National Cancer Institute, outside of Washington. She is also a deputy mayor of Changsha. A stocky woman, she is direct, informed, briskly intelligent, with a sense of humor, and formidably well prepared. We talked at an elaborate dinner with half a dozen of her colleagues; we met the next morning in her office with a graduate student attending to help with translation.

"The major scientific program running right now in China is this one, called 97-3 Program," Professor Cao said. "A major huge program to catch up with the scientific development of the whole world. Started in 1997, March. This program is for basic research. According to the needs of the nation." Technological applications? Or basic science? "Both," she said with a sharp nod. The goal is split in two? "Yes," she said. "I think that the major scientific program is the whole-world program. Not just for China. The second is the urgent requirement for our country's social and economic development."


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The 97-3 Program concentrates research in six areas, agricultural biotechnology, energy, informatics, natural resources and the environment, population and health, and materials science. Cao's own concern is with population and health. In this area the research is divided into 20 fields. She took me through them with the aid of a 33-page position paper she had put together in anticipation of my visit. The list is diverse, the projects ambitious. Yet even the most basic research—in stem cells, for example—has been defined in terms of immediate applications.

Her own working week is half city government, half research. "In particular we'd like to know how the Epstein-Barr virus"—which can cause cancer—"works with the host cells." The questions her group is asking would not be out of place at the National Cancer Institute. Her laboratory has about 20 persons, mostly PhD candidates, with five technicians. Her entire Cancer Research Institute has six laboratories, 50 faculty, some 100 students. Six faculty members are among those Chinese scientists who have returned from abroad. The center is part of the medical school.

"For my lab, I think it is okay. I think we do a very good job," she said. "And also, in my lab we have very good teamwork. They can share the information, share the idea, exchange the information, the discussion." She was deeply influenced by her time at the National Cancer Institute. Her boss in the medical school is a scientist: "He is academy member, 74 years old." Is automatic respect for elders a problem? "No." It doesn't get in the way of the science? I rephrased the question, twice. Each time she sat mum, gave no answer.

Harmony, consensus, respect for authority and for the views of elders: for thousands of years, this set of attitudes has ruled the behavior of individual Chinese. At issue today is the power of a hierarchy based first on seniority and next on connections.

I asked what she saw as the problems. "I think the most important big point is, we should publish more our work in the international journals. So the whole world get the chance to know more what are we doing in China. The major problem is a language problem. Editor always say the English is not native. And they say, you need some native person to help you improve the quality of the paper." She gave me a bibliography of all the biology papers by scientists in China published between 2000 and the summer of 2005 in *Science*, *Nature*, and *Cell*. They numbered 36. Most listed large numbers of coauthors, the largest, 30. Of her own laboratory, she said, "This year we try to publish some good papers in *JBC* and the *PNAS*," the *Journal of Biological Chemistry* and *Proceedings of the National Academy of Sciences*, U.S.

Any more? "Yes. I think we should give up all the low-level repeat work. It doesn't make any sense. It just make more *trash*!"

Yang Ke is executive vice president of the Peking University Health Science Center. (In English she prefers the Western order, given name first.) She is a woman of remarkable charm, perceptiveness, and subtlety, passionate and idealistic about good science: of all the scientists I met, Professor Ke expressed the most acute awareness of the difficulties and pressures Chinese scientists confront. Like Cao Ya, she worked in the United States at the National Cancer Institute, from 1985 to 1988. With her during our interview and at lunch was the center's director of international coöperation, Dong Zhe. "In English, if I have problem, he will help me."

Ke has run a laboratory ever since she returned from the United States in 1988; her current work addresses "mostly esophageal and gastric cancer, which has very high incidence in China." Esophageal cancer has a proven though not simple genetic component. "We're working on a high-incidence population in a relatively isolated rural area of Henan province." She was made vice president for research four years ago and stepped up to her present job two years later. The promotions came, though, "at the time I just got the real feeling of the science. Start harvesting results." She misses that: "I'm less in the lab work, but I'm still struggling not to give up, because I think I am still useful to the students," she said. "At least, I think my students are getting a good training."

The picture of Chinese science presented to the world, she said, has emphasized very rapid development—"and the thing is, we are progressing in right direction. But we still have problems." She said she would discuss these one by one. But first, "Another thing I should say is, my opinion is not official." Indeed, she hoped her impulse to be frank would not be taken amiss.

"The first one. China has really made tremendous effort to enhance science and technology. Because government realized this is the way—at least, one of the way, one of the important way, to make the country strong," she said. "But science is not like steel industry and automobile. It needs time." Education in science has been financed heavily, "but not enough." And education in the sciences must start very young. Grants for research from the ministry, from the Natural Science Foundation, have been increased tenfold or more in the past decade. "But I think the universities should get more support in the basic research because of their advantage in the field and also because of the influence on the students. And I think basic research has strongest

impact on the students in the way of scientific thinking—for which in our culture is relatively weak."

Secondly, "For the technology development…for example, if we want a satellite, it can be organized by the government," she said. "But the problem is, they do emphasize basic science, but in an organizing way"—from the top down—"instead of creating it from the science level. Although a lot of scientists are more and more influential, people still think that we can do it effectively the way as they do it in technical development. That's a problem people have: they cannot wait. They expect your results, second day. They tell scientists, 'You got the money. And you organize a team! Make it big! And the Nobel Prize, tomorrow!' That way!" Yet "of course, it works, as well, because good researchers get more grant in this way. And look at the progress we are making. Now we have some people really understand the science. And they know the rule of the game. And they are serious about their work. But I think in the long term, scientists in basic science should be given more freedom and longer time in the direction and production.

"So I have to jump to the third question. In this society, now, and in the culture, I think Chinese people now emphasize the technology more than science. From beginning, from long time ago in our history, we have the tradition of research for application. That's our culture. For five thousand years.

"Furthermore, in our society—because it's very rapidly developing, economically—the trend of the social system causes a turmoil of thinking. In terms of belief. People are more materialist," she said. "But for the basic science, people have to have very quiet minds. Clear. And focused. And…" Searching for a term, she turned to Dong Zhe. He pursed his lips, then said, "Tolerate the hard work." And the uncertainty. She picked up the exchange: "But the first thing is to be very interested. Curious. Very curious. And then tolerate the loneliness. For a long time. And maybe without any answer."

But, I said, it's not just the individual. "The group," she said. "The collaboration. That's another problem. Difficult. First thing is, because of all these problems, everybody want them to be successful. And everybody think themselves is most important. That is the trend in our society. The second thing is, again, cultural. Chinese people don't want to say negative things at beginning. They don't want to make clear how to divide benefit"—credit—"at beginning. So if it becomes very successful, then people quarrel."

Dong Zhe intervened. "What Professor Ke is saying, it is a Chinese cultural attribute that you want to show your politeness; but on the other hand, you don't state your terms. Sometimes it doesn't matter. But when you are going to harvest your fruits, then the problem comes up. Everyone want to claim they are contributor."

This is an aspect of Chinese culture that is thousands of years old, I said. Both murmured agreement. Ke said, "People respect scientific thinking. But they don't really understand it—most of them, in our culture. I noticed, because I was exposed to Western culture, I noticed in our school—this is a famous medical school—most teachers are teaching the students just according to the book."

Dong Zhe: "She is saying that the Chinese culture doesn't encourage you to have questions in your mind but asks you to follow what the master mind says."

Yang Ke: "Mm-hm. But that starts changing. Because some Chinese understand, what is really—how they can do the science. But still, if you must change the whole country's thinking, it takes a long time." She turned to Dong again, with a burst of rapid Chinese.

He considered for a moment, then said, "The Chinese culture has a long history. So it must have some truth and excellency. However, if we are facing the development of new scientists, it seems that we have to break away from the tradition a little bit. Learn to be sharp and frank."

"That's a problem people have: they cannot wait. They expect your results, second day. They tell scientists, 'You got the money. And you organize a team! Make it big! And the Nobel Prize, tomorrow!'"

How? "It will take time." Ke said. "It is globalization which will make the advantages of Chinese and Western culture integrated. Our well-educated, very promising young people must learn from outside also. If they want to be a scientist." So they go abroad and then come back? "Right." But when they come back, what protects them from the elders? "If we have more and more people coming back. For example, my students go out and come back, they shouldn't have any problem to deal with me."

Dong explained, "I think what Professor Ke is saying, that because of this globalization there is interchange of cultures. So many key research people have been trained abroad." What do they come back to? "If it is one single person, you can't change the situation, but if when they are coming back in a group they become a force." Ke nodded, "Mm-hm." Dong went on, "And they bring in the new ideas. And then they practice all the behaviors of the scientist, beginning a change." Beginning to form a scientific cadre, I said—because the ethos must spread to students and technicians, too.

"Right, right," she said. "So that needs generations. That needs generations. I don't think one generation—"

"Maybe a few generations," Dong Zhe said.

In Shanghai in 2000, two institutes nearly half a century old merged to form the Institute of Biochemistry and Cell Biology. It is one of the largest and best research centers in China. Geneticist Li Zaiping is elderly, genial, a smooth survivor. We met in a large conference room, with colleagues of Li's, including a senior principal investigator studying insulin and the institute's deputy director, Jing Naihe, younger, fluent, intense. Professor Jing had taken his PhD at one of the institute's predecessors and had gone to Japan as a postdoc. Li relied on Jing to do most of the explaining.

Overall, the institute works in molecular, cell, and developmental biology and in biochemistry, but the four laboratory groups have different specializations and somewhat different affiliations. The State Key Laboratory of Molecular Biology, for example, concerned with RNA-protein interactions and regulation of gene expression, is largely funded and overseen by the Ministry of Science and Technology. ("Key laboratory" is a literal translation of the Chinese, meaning very important.) The other laboratory groups are creatures of the Chinese Academy of Sciences.

At the time Li, Jing, and I met, the institute had 194 scientists, with 45 principal investigators. Of the principal investigators, a third were under 45, a third were between 45 and 60, and a third were above 60—"but now that's less," Jing said. The old guys? My remark was less than tactful, and the laughter was uncomfortable. Jing jumped in, nodding at his senior colleagues: "They are, you can see, I think they are young! At least scientifically, right?" I said that in Beijing I had had a graduate student helping me, who when she learned my age said she'd call me "Ye ye," which is Chinese children's talk for "grandpa." This time the laughter was unrestrained. Li Zaiping then said, soberly, "It's difficult to get funding, for old people."

"We have about one staff member for every two graduate students," Jing said. "We have very few postdocs." Why? "Because the good students, after they get the PhD, they go to U.S. to make their postdocs. Although now, from this year, that situation start to change."

The institute is energetically recruiting from the scientific diaspora. Yet how do you persuade the postdocs in America to come back? The question provoked general discussion. Jing said, "We have to give them some funding money. And then give them freedom to do their research. Very important. Of course, they have to be of good quality." The number and quality of the applications is improving markedly, he said. "We give them relatively good salaries, also. And now, in Shanghai, you know, house prices increasing tremendously. This makes recruitment even harder. So we also give them compensation on the house."

But you say you give them freedom. "Well, this is a good question. First of all we give them funding, startup funds. Of course, his research has to be in the overview of our institute. But then he can choose what he wants to do. But he also has the decision to make, how he can get grants. So he has to adjust his research with the importance of related projects." Grants come from the 97-3 Program through the Natural Science Foundation, or through the Chinese Academy. For some time, the academy has also fostered recruitment through the Hundred Talents project. This was specifically designed to provide younger scientists of recognized potential the funding to work as principal investigators altogether independently of the institutional hierarchies.

How does a new group develop the scientific ethos, the sense of community? "Ah. All I can say…," Jing paused. "This is mainly, how I can say, now our institute gradually is adopting a system like the U.S. And because most of the PIs are coming back from the U.S. Now the PI has almost very advanced freedom, how the money he can use, how the people he can hire, and the students he can pick up. All this." Yet he and his colleagues understood, Jing said, that the returning postdoc has no experience as a principal investigator. So they have recently joined up with a group of scientists at some seven associated laboratories, at different American universities, who come for short periods as visiting PIs. And they are trying to develop a way "to find mentors for new PIs. But we have not started yet."

The unique character of Chinese science now and tomorrow can only be understood rightly in its integral relationship to the nation's unique problems; in magnitude and urgency these are unprecedented in world history. It is by no means obvious that they can be adequately addressed. In the attempt, China is suffering unbearable strains: it is experiencing economic, nay, demographic, cultural, social transformation at blinding speed. The sciences are part of that transformation, pulled between basic and applied, between international standards and domestic priorities, between modernity and tradition, between free, curiosity-driven inquiry and hard political realities. Meditating on the situation of Chinese science, Zhang Xianeng at the Ministry of Science and Technology said quietly and simply, "From my point of view, most of the real discovery were from curiosity research. But for this country, we need to solve our problems." In the Chinese setting, to foster the essential ethos of scientific research is not easy. Progress is being made: Yang Ke is right about that. She is right, also, that it will take time, perhaps generations. TR

Horace Freeland Judson is the author of five books, including The Eighth Day of Creation, *a history of molecular biology that was published in 1979 and is still in print.*


David D. Clark

ED QUINN

The Internet Is Broken

The Net's fundamental flaws cost companies billions, impede innovation, and threaten national security. It's time for a clean-slate approach.

By David Talbot

In his office within the gleaming-stainless-steel and orange-brick jumble of MIT's Stata Center, Internet elder statesman and onetime chief protocol architect David D. Clark prints out an old PowerPoint talk. Dated July 1992, it ranges over technical issues like domain naming and scalability. But in one slide, Clark points to the Internet's dark side: its lack of built-in security. In others, he observes that sometimes the worst disasters are caused not by sudden events but by slow, incremental processes—and that humans are good at ignoring problems. "Things get worse slowly. People adjust," Clark noted in his presentation. "The problem is assigning the correct degree of fear to distant elephants."

Today, Clark believes the elephants are upon us. Yes, the Internet has wrought wonders: e-commerce has flourished, and e-mail has become a ubiquitous means of communication. Almost one billion people now use the Internet, and critical industries like banking increasingly rely on it. At the same time, the Internet's shortcomings have resulted in plunging security and a decreased ability to accommodate new technologies. "We are at an inflection point, a revolution point," Clark now argues. And he delivers a strikingly pessimistic assessment of where the Internet will end up without dramatic intervention. "We might just be at the point where the utility of the Internet stalls—and perhaps turns downward."

Indeed, for the average user, the Internet these days all too often resembles New York's Times Square in the 1980s. It was exciting and vibrant, but you made sure to keep your head down, lest you be offered drugs, robbed, or harangued by the insane. Times Square has been cleaned up, but the Internet keeps getting worse, both at the user's level, and—in the view of Clark and others—deep within its architecture. Over the years, as Internet applications proliferated—wireless devices, peer-to-peer file-sharing, telephony—companies and network engineers came up with ingenious and expedient patches, plugs, and workarounds. The result is that the originally simple communications technology has become a complex and convoluted affair. For all of the Internet's wonders, it is also difficult to manage and more fragile with each passing day.

That's why Clark argues that it's time to rethink the Internet's basic architecture, to potentially start over with a fresh design—and equally important, with a plausible strategy for proving the design's viability, so that it stands a chance of implementation. "It's not as if there is some killer technology at the protocol or network level that we somehow failed to include," says Clark. "We need to take all the technologies we already know and fit them together so that we get a different overall system. This is not about building a technology innovation that changes the world but about architecture—pulling the pieces together in a different way to achieve high-level objectives."

Just such an approach is now gaining momentum, spurred on by the National Science Foundation. NSF managers are working to forge a five-to-seven-year plan estimated to cost $200 million to $300 million in research funding to develop clean-slate architectures that provide security, accommodate new technologies, and are easier to manage. They also hope to develop an infrastructure that can be used to prove that the new system is really better than the current one. "If we succeed in what we are trying to do, this is bigger than anything we, as a research community, have done in computer science so far," says Guru Parulkar, an NSF program manager involved with the effort. "In terms of its mission and vision, it is a very big deal. But now we are just at the beginning. It has the potential to change the game. It could take it to the next level in realizing what the Internet could be that has not been possible because of the challenges and problems."

"We are at an inflection point, a revolution point," says David Clark. "We might just be at the point where the utility of the Internet stalls—and perhaps turns downward."

Firewall Nation

When AOL updates its software, the new version bears a number: 7.0, 8.0, 9.0. The most recent version is called AOL 9.0 Security Edition. These days, improving the utility of the Internet is not so much about delivering the latest cool application; it's about survival. In August, IBM released a study reporting that "virus-laden e-mails and criminal driven security attacks" leapt by 50 percent in the first half of 2005, with government and the financial-services, manufacturing, and health-care industries in the crosshairs. In July, the Pew Internet and American Life Project reported that 43 percent of U.S. Internet users—59 million adults—reported having spyware or adware on their computers, thanks merely to visiting websites. (In many cases, they learned this from the sudden proliferation of error messages or freeze-ups.) Fully 91 percent had adopted some defensive behavior—avoiding certain kinds of websites, say, or not downloading software. "Go to a neighborhood bar, and people are talking about firewalls. That was just not true three years ago," says Susannah Fox, associate director of the Pew project.

Then there is spam. One leading online security company, Symantec, says that between July 1 and December 31, 2004, spam surged 77 percent at companies that Symantec monitored. The raw numbers are staggering: weekly spam totals on average rose from 800 million to more than 1.2 billion messages, and 60 percent of all e-mail was spam, according to Symantec. But perhaps most menacing of all are "botnets"—collections of computers hijacked by hackers to do remote-control tasks like sending spam or attacking websites. This kind of wholesale hijacking—made more potent by wide adoption of always-on broadband connections—has spawned hard-core crime: digital extortion. Hackers are threatening destructive attacks against companies that don't meet their financial demands. According to a study by a Carnegie Mellon University researcher, 17 of 100 companies surveyed had been threatened with such attacks.

Simply put, the Internet has no inherent security architecture—nothing to stop viruses or spam or anything else. Protections like firewalls and antispam software are add-ons, security patches in a digital arms race. The President's Information Technology Advisory Committee, a group stocked with a who's who of infotech CEOs and academic researchers, says the situation is bad and getting worse. "Today, the threat clearly is growing," the council wrote in a report issued in early 2005. "Most indicators and studies of the frequency, impact, scope, and cost of cyber security incidents—among both organizations and individuals—point to continuously increasing levels and varieties of attacks." And we haven't even seen a real act of cyberterror, the "digital Pearl Harbor" memorably predicted by former White House counterterrorism czar Richard Clarke in 2000 *(see "A Tangle of Wires," p. 80)*. Consider the nation's electrical grid: it relies on continuous network-based communications between power plants and grid managers to maintain a balance between production and demand. A well-placed attack could trigger a costly blackout that would cripple part of the country. The conclusion of the advisory council's report could not have been starker: "The IT infrastructure is highly vulnerable to premeditated attacks with potentially catastrophic effects."

The system functions as well as it does only because of "the forbearance of the virus authors themselves," says

Jonathan Zittrain, who cofounded the Berkman Center for Internet and Society at Harvard Law School and holds the Chair in Internet Governance and Regulation at the University of Oxford. “With one or two additional lines of code…the viruses could wipe their hosts’ hard drives clean or quietly insinuate false data into spreadsheets or documents. Take any of the top ten viruses and add a bit of poison to them, and most of the world wakes up on a Tuesday morning unable to surf the Net—or finding much less there if it can.”

Patchwork Problem

The Internet’s original protocols, forged in the late 1960s, were designed to do one thing very well: facilitate communication between a few hundred academic and government users. The protocols efficiently break digital data into simple units called packets and send the packets to their destinations through a series of network routers. Both the routers and PCs, also called nodes, have unique digital addresses known as Internet Protocol or IP addresses. That’s basically it. The system assumed that all users on the network could be trusted and that the computers linked by the Internet were mostly fixed objects.

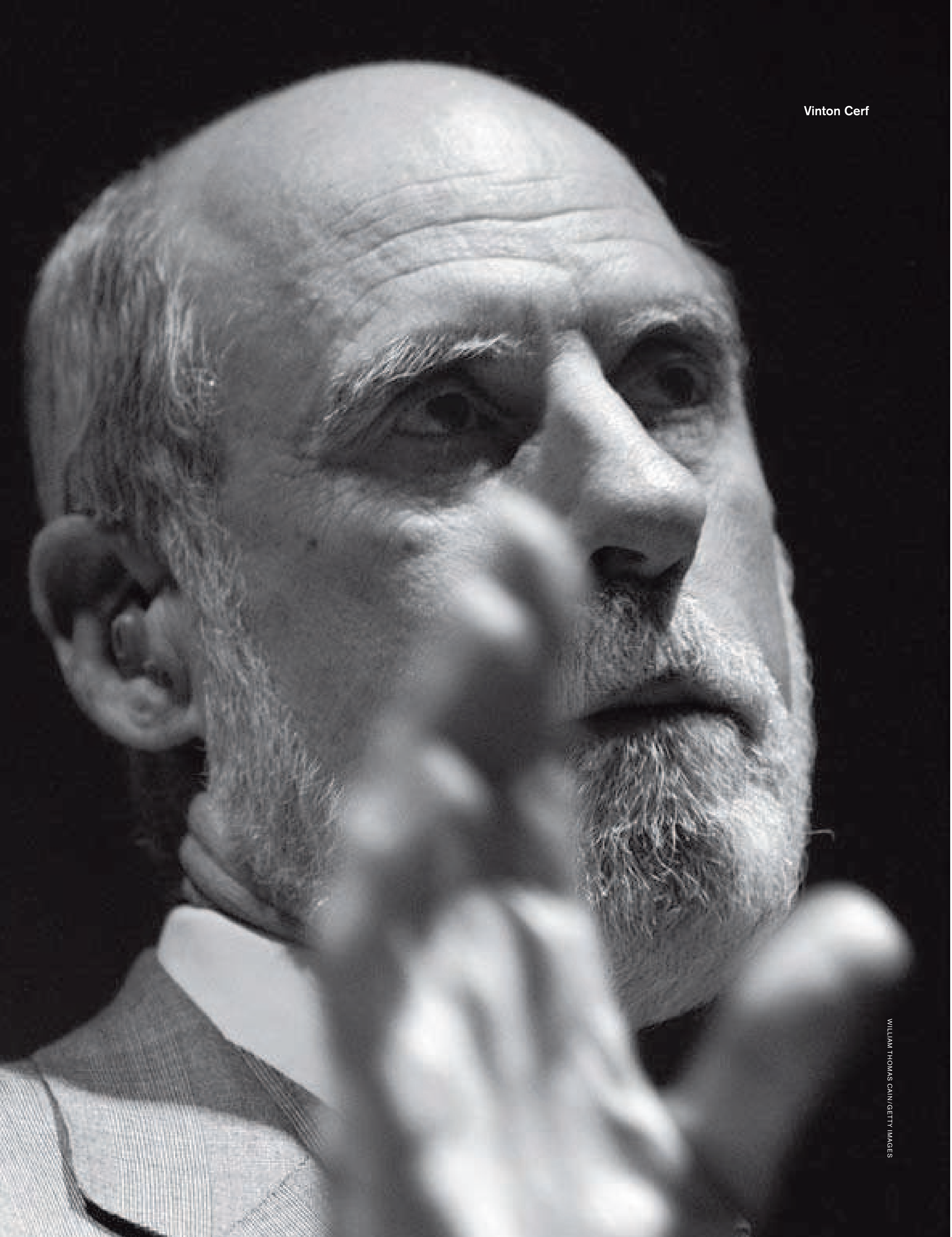
The Internet’s design was indifferent to whether the information packets added up to a malicious virus or a love letter; it had no provisions for doing much besides getting the data to its destination. Nor did it accommodate nodes that moved—such as PDAs that could connect to the Internet at any of myriad locations. Over the years, a slew of patches arose: firewalls, antivirus software, spam filters, and the like. One patch assigns each mobile node a new IP address every time it moves to a new point in the network.

Clearly, security patches aren’t keeping pace. That’s partly because different people use different patches and not everyone updates them religiously; some people don’t have any installed. And the most common mobility patch—the IP addresses that constantly change as you move around—has downsides. When your mobile computer has a new identity every time it connects to the Internet, the websites you deal with regularly won’t know it’s you. This means, for example, that your favorite airline’s Web page might not cough up a reservation form with your name and frequent-flyer number already filled out. The constantly changing address also means you can expect breaks in service if you are using the Internet to, say, listen to a streaming radio broadcast on your PDA. It also means that someone who commits a crime online using a mobile device will be harder to track down.

In the view of many experts in the field, there are even more fundamental reasons to be concerned. Patches create an ever more complicated system, one that becomes harder to manage, understand, and improve upon. “We’ve been on a track for 30 years of incrementally making improvements to the Internet and fixing problems that we see,” says Larry Peterson, a computer scientist at Princeton University. “We see vulnerability, we try to patch it. That approach is one that has worked for 30 years. But there is reason to be concerned. Without a long-term plan, if you are just patching the next problem you see, you end up with an increasingly complex and brittle system. It makes new services difficult to employ. It makes it much harder to manage because of the added complexity of all these point solutions that have been added. At the same time, there is concern that we will hit a dead end at some point. There will be problems we can’t sufficiently patch.”

The patchwork approach draws complaints even from the founder of a business that is essentially an elaborate and ingenious patch for some of the Internet’s shortcomings. Tom Leighton is cofounder and chief scientist of Akamai, a company that ensures that its clients’ Web pages and applications are always available, even if huge numbers of customers try to log on to them or a key fiber-optic cable is severed. Akamai closely monitors network problems, strategically stores copies of a client’s website at servers around the world, and accesses those servers as needed. But while his company makes its money from patching the Net, Leighton says the whole system needs fundamental architectural change. “We are in the mode of trying to plug holes in the dike,” says Leighton, an MIT mathematician who is also a member of the President’s Information Technology Advisory Committee and chair of its Cyber Security Subcommittee. “There are more and more holes, and more resources are going to plugging the holes, and there are less resources being devoted to fundamentally changing the game, to changing the Internet.”

When Leighton says “resources,” he’s talking about billions of dollars. Take Microsoft, for example. Its software mediates between the Internet and the PC. These days, of the $6 billion that Microsoft spends annually on research and development, approximately one-third, or $2 billion, is directly spent on security efforts. “The evolution of the Internet, the development of threats from the Internet that could attempt to intrude on systems—whether Web servers, Web browsers, or e-mail-based threats—really changed the equation,” says Steve Lipner, Microsoft’s director of security strategy and engineering strategy. “Ten years ago, I think people here in the industry were designing software for new features, new performance, ease of use, what have you. Today, we train everybody for security.” Not only does this focus on security siphon resources from other research, but it can even hamper research that does get funded. Some innovations have been kept in the lab, Lipner says, because Microsoft couldn’t be sure they met security standards.



Vinton Cerf

WILLIAM THOMAS CAIN/GETTY IMAGES

Of course, some would argue that Microsoft is now scrambling to make up for years of selling insecure products. But the Microsoft example has parallels elsewhere. Eric Brewer, director of Intel's Berkeley, CA, research lab, notes that expenditures on security are like a "tax" and are "costing the nation billions and billions of dollars." This tax shows up as increased product prices, as companies' expenditures on security services and damage repair, as the portion of processor speed and storage devoted to running defensive programs, as the network capacity consumed by spam, and as the costs to the average person trying to dodge the online minefield of buying the latest firewalls. "We absolutely can leave things alone. But it has this continuous 30 percent tax, and the tax might go up," Brewer says. "The penalty for not [fixing] it isn't immediately fatal. But things will slowly get worse and might get so bad that people won't use the Internet as much as they might like."

The existing Internet architecture also stands in the way of new technologies. Networks of intelligent sensors that collectively monitor and interpret things like factory conditions, the weather, or video images could change computing as much as cheap PCs did 20 years ago. But they have entirely different communication requirements. "Future networks aren't going to be PCs docking to mainframes. It's going to be about some car contacting the car next to it. All of this is happening in an embedded context. Everything is machine to machine rather than people to people," says Dipankar Raychaudhuri, director of the Wireless Information Network Laboratory (Winlab) at Rutgers University. With today's architecture, making such a vision reality would require more and more patches.

The collapse of the Net has been predicted for a decade and hasn't happened, notes Vinton Cerf. The real security problem, he says, is that operating systems don't protect themselves. "An argument could be made, 'Why does the network have to do that?'"

Architectural Digest

When Clark talks about creating a new architecture, he says the job must start with the setting of goals. First, give the medium a basic security architecture—the ability to authenticate whom you are communicating with and prevent things like spam and viruses from ever reaching your PC. Better security is "the most important motivation for this redesign," Clark says. Second, make the new architecture practical by devising protocols that allow Internet service providers to better route traffic and collaborate to offer advanced services without compromising their businesses. Third, allow future computing devices of any size to connect to the Internet—not just PCs but sensors and embedded processors. Fourth, add technology that makes the network easier to manage and more resilient. For example, a new design should allow all pieces of the network to detect and report emerging problems—whether technical breakdowns, traffic jams, or replicating worms—to network administrators.

The good news is that some of these goals are not so far off. NSF has, over the past few years, spent more than $30 million supporting and planning such research. Academic and corporate research labs have generated a number of promising technologies: ways to authenticate who's online; ways to identify criminals while protecting the privacy of others; ways to add wireless devices and sensors. While nobody is saying that any single one of these technologies will be included in a new architecture, they provide a starting point for understanding what a "new" Internet might actually look like and how it would differ from the old one.

Some promising technologies that might figure into this new architecture are coming from PlanetLab, which Princeton's Peterson has been nurturing in recent years *(see "The Internet Reborn," October 2003)*. In this still-growing project, researchers throughout the world have been developing software that can be grafted onto today's dumb Internet routers. One example is software that "sniffs" passing Internet traffic for worms. The software looks for telltale packets sent out by worm-infected machines searching for new hosts and can warn system administrators of infections. Other software prototypes detect the emergence of data traffic jams and come up with more efficient ways to reroute traffic around them. These kinds of algorithms could become part of a fundamental new infrastructure, Peterson says.

A second set of technologies could help authenticate Internet communications. It would be a huge boon to Internet security if you could be sure an e-mail from your bank is really from your bank and not a scam artist, and if the bank could be sure that when someone logs in to your account, that person is really you and not someone who stole your account number.

Today, the onus of authentication is on the Internet user, who is constantly asked to present information of various kinds: passwords, social-security numbers, employee ID numbers, credit card numbers, frequent-flyer numbers, PIN numbers, and so on. But when millions of users are

constantly entering these gate-opening numbers, it makes it that much easier for spyware, or a thief sniffing wireless Internet traffic, to steal, commit fraud, and do damage.

One evolving solution, developed by Internet2—a research consortium based in Ann Arbor, MI, that develops advanced Internet technologies for use by research laboratories and universities—effectively creates a middleman who does the job. Called Shibboleth, the software mediates between a sender and a recipient; it transmits the appropriate ID numbers, passwords, and other identifying information to the right recipients for you, securely, through the centralized exchange of digital certificates and other means. In addition to making the dispersal of information more secure, it helps protect privacy. That's because it discloses only the "attributes" of a person pertinent to a particular transaction, rather than the person's full "identity."

Right now, Shibboleth is used by universities to mediate access to online libraries and other resources; when you log on, the university knows your "attribute"—you are an enrolled student—and not your name or other personal information. This basic concept can be expanded: your employment status could open the gates to your company's servers; your birth date could allow you to buy wine online. A similar scheme could give a bank confidence that online account access is legitimate and conversely give a bank customer confidence that banking communications are really from the bank.

Shibboleth and similar technologies in development can, and do, work as patches. But some of their basic elements could also be built into a replacement Internet architecture. "Most people look at the Internet as such a dominant force, they only think how they can make it a little better," Clark says. "I'm saying, 'Hey, think about the future differently. What should our communications environment of 10 to 15 years from now look like? What is your goal?'"

The Devil We Know

It's worth remembering that despite all of its flaws, all of its architectural kluginess and insecurity and the costs associated with patching it, the Internet still gets the job done. Any effort to implement a better version faces enormous practical problems: all Internet service providers would have to agree to change all their routers and software, and someone would have to foot the bill, which will likely come to many billions of dollars. But NSF isn't proposing to abandon the old network or to forcibly impose something new on the world. Rather, it essentially wants to build a better mousetrap, show that it's better, and allow a changeover to take place in response to user demand.

To that end, the NSF effort envisions the construction of a sprawling infrastructure that could cost approximately $300 million. It would include research labs across the United States and perhaps link with research efforts abroad, where new architectures can be given a full workout. With a high-speed optical backbone and smart routers, this test bed would be far more elaborate and representative than the smaller, more limited test beds in use today. The idea is that new architectures would be battle tested with real-world Internet traffic. "You hope that provides enough value added that people are slowly and selectively willing to switch, and maybe it gets enough traction that people will switch over," Parulkar says. But he acknowledges, "Ten years from now, how things play out is anyone's guess. It could be a parallel infrastructure that people could use for selective applications."

> **Whether or not the NSF comes up with a viable new Internet architecture, says Jonathan Zittrain, the growing pressures on the medium are fostering legal, corporate, and technological responses likely to make the Internet "more secure—and less interesting."**

Still, skeptics claim that a smarter network could be even more complicated and thus failure-prone than the original bare-bones Internet. Conventional wisdom holds that the network should remain dumb, but that the smart devices at its ends should become smarter. "I'm not happy with the current state of affairs. I'm not happy with spam; I'm not happy with the amount of vulnerability to various forms of attack," says Vinton Cerf, one of the inventors of the Internet's basic protocols, who recently joined Google with a job title created just for him: chief Internet evangelist. "I do want to distinguish that the primary vectors causing a lot of trouble are penetrating holes in operating systems. It's more like the operating systems don't protect themselves very well. An argument could be made, 'Why does the network have to do that?'"

According to Cerf, the more you ask the network to examine data—to authenticate a person's identity, say, or search for viruses—the less efficiently it will move the data around. "It's really hard to have a network-level thing do this stuff, which means you have to assemble the packets into something bigger and thus violate all the protocols," Cerf says. "That takes a heck of a lot of resources." Still, Cerf sees value in the new NSF initiative. "If Dave Clark… sees some notions and ideas that would be dramatically

Foundations for a New Infrastructure

The NSF's emerging effort to forge a clean-slate Internet architecture will draw on a wide body of existing research. Below is a sampling of major efforts aimed at improving everything from security to wireless communications.

PROJECT/HOME INSTITUTION	FOCUS
PLANETLAB/ Princeton University Princeton, NJ	Creating an Internet "overlay network" of hardware and software—currently 630 machines in 25 countries—that performs functions ranging from searching for worms to optimizing traffic.
EMULAB/ University of Utah Salt Lake City, UT	A software and hardware test bed that provides researchers a simple, practical way to emulate the Internet for a wide variety of research goals.
DETER/ University of Southern California Information Sciences Institute Marina del Rey, CA	A research test bed where researchers can safely launch simulated cyber-attacks, analyze them, and develop defensive strategies, especially for critical infrastructure.
WINLAB (Wireless Information Network Laboratory)/Rutgers University New Brunswick, NJ	Develops wireless networking architectures and protocols, aimed at deploying the mobile Internet. Performs research on everything from high-speed modems to spectrum management.

better than what we have, I think that's important and healthy," Cerf says. "I sort of wonder about something, though. The collapse of the Net, or a major security disaster, has been predicted for a decade now." And of course no such disaster has occurred—at least not by the time this issue of *Technology Review* went to press.

The NSF effort to make the medium smarter also runs up against the libertarian culture of the Internet, says Harvard's Zittrain. "The NSF program is a worthy one in the first instance because it begins with the premise that the current Net has outgrown some of its initial foundations and associated tenets," Zittrain says. "But there is a risk, too, that any attempt to rewrite the Net's technical constitution will be so much more fraught, so much more self-conscious of the nontechnical matters at stake, that the cure could be worse than the problem."

Still, Zittrain sees hazards ahead if some sensible action isn't taken. He posits that the Internet's security problems, and the theft of intellectual property, could produce a counterreaction that would amount to a clampdown on the medium—everything from the tightening of software makers' control over their operating systems to security lockdowns by businesses. And of course, if a "digital Pearl Harbor" does occur, the federal government is liable to respond reflexively with heavy-handed reforms and controls. If such tightenings happen, Zittrain believes we're bound to get an Internet that is, in his words, "more secure—and less interesting."

But what all sides agree on is that the Internet's perennial problems are getting worse, at the same time that society's dependence on it is deepening. Just a few years ago, the work of researchers like Peterson didn't garner wide interest outside the networking community. But these days, Clark and Peterson are giving briefings to Washington policymakers. "There is recognition that some of these problems are potentially quite serious. You could argue that they have always been there," Peterson says. "But there is a wider recognition in the highest level of the government that this is true. We are getting to the point where we are briefing people in the president's Office of Science and Technology Policy. I specifically did, and other people are doing that as well. As far as I know, that's pretty new."

Outside the door to Clark's office at MIT, a nametag placed by a prankster colleague announces it to be the office of Albus Dumbledore—the wise headmaster of the Hogwarts School of Witchcraft and Wizardry, a central figure in the Harry Potter books. But while Clark in earlier years may have wrought some magic, helping transform the original Internet protocols into a robust communications technology that changed the world, he no longer has much control over what happens next.

But "because we don't have power, there is a greater chance that we will be left alone to try," he says. And so Clark, like Dumbledore, clucks over new generations of technical wizards. "My goal in calling for a fresh design is to free our minds from the current constraints, so we can envision a different future," he says. "The reason I stress this is that the Internet is so big, and so successful, that it seems like a fool's errand to send someone off to invent a different one." Whether the end result is a whole new architecture—or just an effective set of changes to the existing one—may not matter in the end. Given how entrenched the Internet is, the effort will have succeeded, he says, if it at least gets the research community working toward common goals, and helps "impose creep in the right direction." TR

David Talbot is Technology Review*'s chief correspondent.*

MRI: A Window on the Brain

Advances in brain imaging could lead to improved diagnosis of psychiatric ailments, better drugs, and earlier help for learning disorders.

By Paul Raeburn

When Bradley Peterson, a psychiatrist and researcher at Columbia University, offered to scan my brain with a magnetic resonance imager the size of a small Airstream trailer, I immediately said yes. I spent 10 minutes filling out a page-long checklist (I lied on the question asking whether I was claustrophobic) and another few minutes emptying my pockets and getting rid of keys, wristwatch, and pen, which could become missiles inside the MRI's potent magnetic field.

I lay down on a narrow pallet that slid into the machine like a drawer in a morgue. The machine groaned and clanged as it peered inside my skull, then fell silent. With a gentle whir, the pallet slid out, and I relaxed. In about the time it takes to burn a few CDs on my laptop, Peterson was leaning over a screen, showing me a detailed black-and-white image of my brain.

Brain scans like the one I had are now routine, used for everything from detecting signs of stroke to searching out suspected tumors. But researchers like Peterson are pushing MRI technology further than anyone once thought it could go. In the last decade or so, MRI has been retooled to reveal not only the anatomy of the brain but also the way the brain works.

While conventional MRI scans, like the one Peterson gave me, reveal physiological structures, a variation called functional MRI (fMRI) can now also image blood flow over time, allowing researchers to see which areas of the brain are active during certain tasks. Indeed, fMRI studies over the last few years have provided researchers with startling images of the brain actually at work. A yet newer extension is MRI spectroscopy, another kind of functional imaging that monitors the activity of particular chemicals in the brain—providing different clues to brain function than fMRI does. And most recently, researchers have pioneered an MRI technique called diffusion tensor imaging (DTI) that produces 3-D images of the frail, spidery network of wires that connects one part of the brain to another.

MRI has become, says Robert Desimone, director of the McGovern Institute for Brain Research at MIT, "the most powerful tool for studying the human brain. I liken it to the invention of the telescope for astronomers." Desimone notes that the arrival of the telescope did not immediately revolutionize the scientific understanding of the universe. That took time, as researchers learned how to use their new tool. The same thing is happening with MRI, Desimone says. Researchers are just now beginning to realize the potential of these techniques, which were first widely used on humans about 15 years ago. "You're seeing a lot of excitement in the field," says Desimone.

Several technical advances have contributed to MRI's improvement. Topping the list is the development of more-powerful MRI magnets, which enable more-detailed, higher-resolution scans. What megapixels are for a digital camera, teslas, a measure of magnetic-field strength, are for MRIs: the more you have, the better the quality of the image. The newest MRIs generate magnetic fields of about seven teslas, many thousands of times stronger than Earth's magnetic field and at least twice as strong as those typically used in hospitals. (Some research centers, including the McGovern Institute, have 9.4-tesla MRI scanners for animal studies.) Another key development is a succession of ever more complex methods of computer analysis. These allow researchers to extract more and better information from scanner data and have improved not just fMRI but also MRI spectroscopy and DTI.

TIM MCGUIRE/CORBIS

The ultimate aim of brain imaging research is to help explain how the billions of neurons and connections in the brain give rise to thought. But researchers are also applying the new MRI techniques to a more practical, immediate goal: improving the diagnosis and treatment of mental illnesses and learning disorders. The hope is that MRI imaging will provide far more accurate diagnosis of psychiatric diseases whose symptoms can resemble each other, preventing years of suffering for patients put on the wrong medications.

As part of this effort, researchers are using MRI to investigate the causes not only of psychiatric ailments but of all kinds of brain abnormalities and learning disorders, including those often found in children born prematurely. And while attempts to use brain imaging to improve psychiatric health care have met with little success over the last decade, the new MRI technologies—in essence, far stronger telescopes on the mind—are providing fresh hope of finding better ways to intervene.

Bipolar Fingerprint

One of the leaders in the effort to enlist MRI in the diagnosis and treatment of psychiatric ailments is John Port at the Mayo Clinic in Rochester, MN. Port is a neuroradiologist who began his career by studying electrical engineering and computer science at MIT and later earned a PhD in cell biology and an MD from the University of Illinois. So he's in a good position to research both basic MRI technology and its applications to medicine.

Port's work on MRI could have broad application in psychiatry, but for now he is concentrating on his particular interest: bipolar disorder. Also called manic-depression, bipolar disorder is characterized by mood swings from wild exuberance to profound depression, with periods of stability in between. X-rays or conventional MRIs show no difference between the brains of people with bipolar disorder and those without it; medical journals are littered with failed attempts to use imaging to find distinctive signs of the disease. Port thinks a lot of those attempts were scientifically flawed. "I have a list of pet peeves a mile long," he says. "There are a million studies, but the patients might be on six different medications. So when you see something different, is it the meds? Or is something going on?" Another problem with many earlier studies, he says, is that they included too few patients. "You can't tell anything from 10 patients. A lot of the research hasn't been as rigorous as it should be."

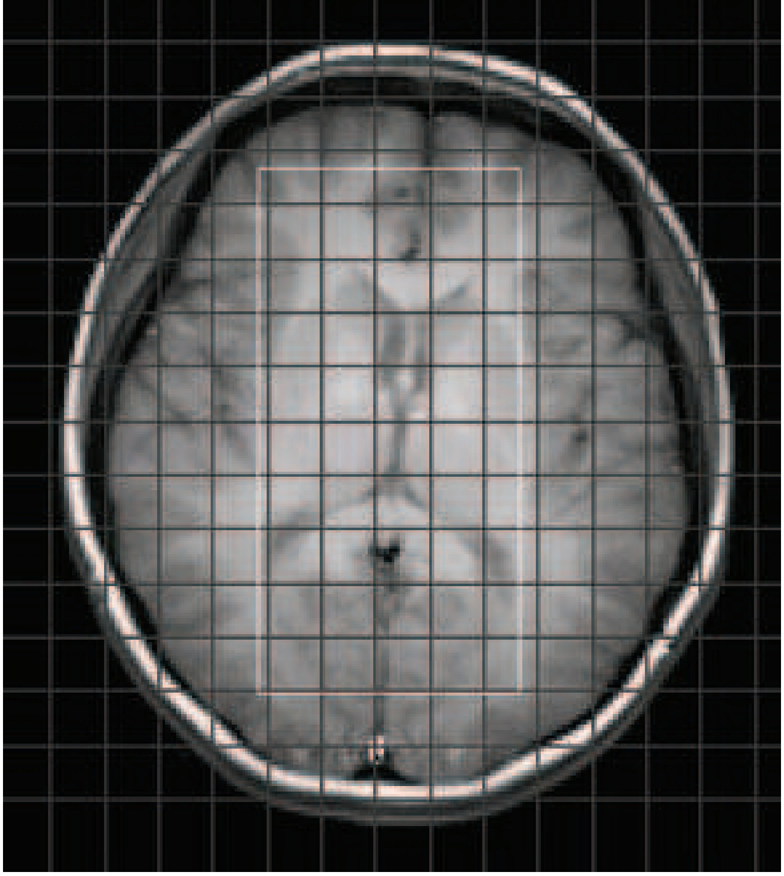
Indeed, despite years of work, neuroscientists still do not know what causes bipolar disorder, or exactly which parts of the brain are involved. That lack of knowledge has severely hampered the search for safer and more effective ways to treat the disease. The principal drugs for bipolar disorder, lithium and Depakote, have been around for decades. Both were discovered by accident, when researchers trying to do something else noticed that the drugs eased the symptoms of patients with bipolar disorder. And though the drugs can be reasonably effective in some people, doctors have no idea how they work or which patients are most likely to benefit. In order to find better pharmaceuticals, researchers need to be able to target the exact mechanisms or structures involved in bipolar disorder.

Pinpointing the mechanisms could also lead to more accurate evaluation of the disorder. Often, diagnosis in psychiatry is done by a kind of trial and error, in which a psychiatrist makes an educated guess based on the behavior or self-reported symptoms of a patient, prescribes a medication, and sees whether or not it helps. If it doesn't, the psychiatrist considers a different diagnosis and a different medication, until something begins to work. "What psychiatrists need is some test that will give them the answer: this patient has the disease or doesn't," says Port. He and other researchers hope MRI scanners will offer the definitive diagnosis. And for those in the mental-health profession, that would change everything. "I'm dedicating the rest of my career to coming up with an imaging test that will help psychiatrists diagnose" bipolar disorder and other illnesses, Port says.

> If the Mayo Clinic's John Port is correct and the brain scanning technique proves itself, it would be a landmark in psychiatric research: a diagnostic test for bipolar disorder. And if the technique works for bipolar disorder, it could be adaptable to other psychiatric illnesses.

Port is one of many researchers now experimenting with MRI spectroscopy, in which software produces an image of the brain based on a spectroscopic scan. The image is made up of individual data points called voxels, cubes analogous to the pixels in a 2-D computer image. Each corresponds to a volume about the size of a kidney bean. For each voxel, Port gets a reading on the presence or absence of certain chemicals that are indicators of brain function.

To understand how MRI spectroscopy works, it's necessary to understand a bit about how magnetic resonance imaging works more generally. MRI scanners pick up extremely faint electromagnetic signals coming from protons in the atoms of molecules that make up the body's tissues—in this case, brain tissue. "Think of it like listening



COURTESY OF JOHN PORT

BIPOLAR DISORDER

Mayo Clinic researcher John Port is using magnetic resonance spectroscopic imaging to look for physiological changes associated with bipolar disorder. Port first stimulates a localized region of the brain (white box), then divides the brain into 3-D sections (gray lines) called voxels. Each voxel contains information on concentrations of metabolites in its corresponding section of brain tissue. The studies have so far revealed that there are characteristic concentrations of metabolites in patients with bipolar disorder.

for a pin drop in a thunderstorm," Port says. Each proton has a magnetic field that points in a certain direction, as the earth's does. When the MRI is turned on, its magnet aligns the protons' magnetic fields in the same direction. Bursts of radio frequency energy temporarily knock some of the protons out of alignment. When the protons snap back into place, they release energy, generating a minuscule signal that the MRI's detectors can pick up. By flipping the protons different ways and measuring various properties of those flips, including the time they take, researchers can identify various tissues and chemicals in the brain.

Using MRI spectroscopy, Port can measure levels of chemicals such as n-acetyl aspartate, which is found only in neurons, or glutamate, which stimulates nerve-cell activity. When Port used the technique across many areas of the brain in bipolar patients and compared the results to those from healthy controls, he came up with a chemical fingerprint that seemed to be an indicator of bipolar disorder. "When we compared all the bipolar patients in any mood state with their matched normal control subjects, we found that two areas of the brain were significantly different," Port says. Port and his team also identified changes in many regions of the brains of people with bipolar disorder that indicated whether they were in a manic state or depressed. "We found a chemical measure of the mood state," he says.

So has Port found the long-sought diagnostic test for bipolar disorder? Does his chemical fingerprint reliably identify people who have bipolar disorder and exclude those who don't?

Maybe, but he can't be sure yet. "We think we're on to something good," he says, but "we have to check it and make sure it will be clinically useful." It's a question of trying the technique with enough patients to be sure that it is statistically valid—that it won't produce too many false positives or false negatives. It doesn't have to be perfect, but it has to be good enough to add useful information to what psychiatrists can discern through their traditional methods of diagnosis, interviews, and analyses of patient histories. If Port is correct, however, and the technique proves itself, it would be a landmark in psychiatric research: a diagnostic test for bipolar disorder. And if the technique works with bipolar disorder, it could be adaptable to other psychiatric illnesses.

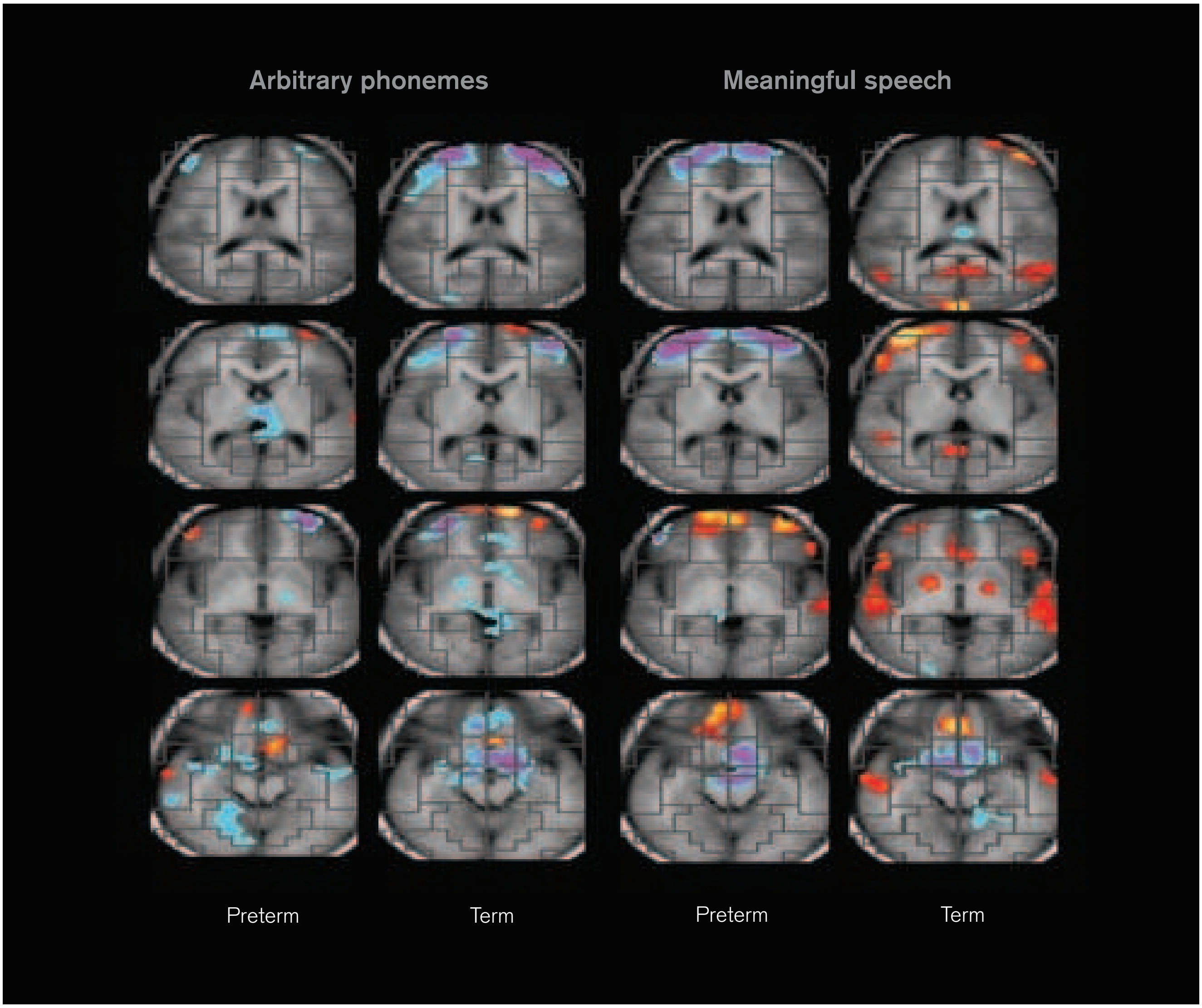
Port and others are also experimenting with diffusion tensor imaging. DTI measures water diffusion in the brain. Water flows through the brain as it does anywhere else—along the path of least resistance. In the brain, that's along the axons, the neurons' long tails, which convey electrical signals to other neurons. (It's from the fatty, white insulation that surrounds most axons that "white matter" takes its name; the rest of the neuron, and uninsulated axons, together constitute "gray matter.") Port is just beginning to research the technique. But eventually researchers will be able to use "DTI clinically to look for diseases that interfere with white matter—amyotrophic lateral sclerosis [Lou Gehrig's disease] and schizophrenia," Port says.

Diagnosing Development

The techniques Port is studying, if they prove successful, will be used in diagnosing people already showing signs of mental illness. But what about others who are predisposed to problems but have not yet begun to exhibit symptoms? Can the MRI technology help to find these people so that they can be helped before symptoms appear?

At Columbia, Peterson is trying to answer that question. He and collaborators are among the first to scan the brains of premature infants—sometimes within days of their birth. The aim is to catalogue the types of brain abnormalities they discover and to devise ways to intervene earlier than ever before to try to correct or compensate for them.

Peterson first became interested in the complications of premature birth about 10 years ago, when he was beginning his psychiatric research at Yale University. He had discovered



COURTESY OF BRADLEY PETERSON

LANGUAGE PROCESSING

Brain images produced by Columbia University's Bradley Peterson show that children who are born prematurely may have more problems processing language than children born at term. The scans above, from top to bottom, show different slices of the brain. The two columns on the left show brain activity in preterm and term children listening to arbitrary sequences of phonemes, or meaningless speech; the two columns on the right show the brain activity of children listening to meaningful speech. The results indicate that the brain activity of preterm children listening to meaningful language resembles that of normal children listening to meaningless speech.

something very unusual in the brains of people with Tourette's syndrome. Most of us have asymmetries in our brains—the left side doesn't exactly match the right. Most of us also have one eye that's bigger than the other (as portrait photographers will point out) and other minor asymmetries. But the brains of people with Tourette's syndrome were different. "In the Tourette's brain, there seemed to be an absence of asymmetry," Peterson says. A similar absence of asymmetry had been observed in animals that survived complicated births. Peterson decided to look at children who had been born prematurely. Like Port, he is using the newest MRI technologies to try to obtain information that hasn't been available before.

There was a reason for his interest. Children born prematurely are at greater risk for learning disabilities and even psychiatric illnesses. Understanding how their brains are different should lead to new ways to help them.

As it happened, Laura Rowe Ment, a pediatric neurologist at Yale, was following a group of 500 premature children born between 1989 and 1992 as part of an ongoing study. Peterson and Ment set up a collaboration. "There were imaging reports suggesting various kinds of problems in the brain—in terms of brain development. But they were uncontrolled, the numbers were small—they were impressionistic," says Peterson. Even given their smaller body size, premature kids tend to have disproportionately small heads. "The guess was that brain size would be reduced"

later in life, says Peterson. Researchers also speculated that there would be damage to the white matter. Ment's kids, who were then about eight years old, were especially useful because she and her colleagues had documented everything that had happened to them since they were born.

The first thing Peterson did was use the MRI scanner to determine the size of the eight-year-old children's brains. The guess was right—their brains were smaller than normal. But the decrease in size occurred only in certain brain regions—the parts of the cortex that govern movement, vision, language, memory, and visual and spatial reasoning. "These regions were dramatically smaller," Peterson says. The other parts of their brains were normal size, or close to it. The second guess—about damage to white matter—also proved accurate. There was less white matter in the motor regions of the children's brains, meaning there were relatively few wiring connections there. And the reduction in volume correlated with IQ scores. "The bigger the abnormality—the more abnormal it was in all these regions—the lower their IQ was," Peterson says.

The question then was, Did these abnormalities arise at or before birth or sometime later? Peterson started scanning normal and premature infants. The scans of premature newborns showed that they had the same brain abnormalities as the eight-year-olds. "It was so distinctive, the pattern of abnormalities, it's almost impossible to look at a scan and not be able to tell this is a premature child," Peterson says. One of the most salient differences was in the size of the tiny cavities in the brain known as ventricles. "The ventricles are massively dilated, about four times larger in the prematurely born kids than in the term children," Peterson says. "We saw that in eight-year-olds and in the infants. The tissue around those ventricles is really damaged....It suggests that these babies are having problems in development even before they're born." Peterson followed the newborns for two years and then tested them with a kind of IQ test meant for toddlers. The earlier they were born, the more immature their brains were at birth. And the more immature their brains, the lower their intelligence scores.

To neuroscientists, the discovery that premature kids had brain abnormalities made sense. Much of the brain's growth and development occurs during the last half of pregnancy. Neurons begin life clumped near the center of what will become the brain but soon start to migrate outward. Glial cells, which help neurons communicate, go through a period of explosive growth, accounting for most of the brain's increase in weight. The neurons extend meandering tentacles, seeking connections with other cells. Billions of connections are made during the last weeks of pregnancy. The axons then develop their coats of white, fatty insulation. By this time, the brain is massively overdeveloped, with far too many wires and connections. So it begins cutting back. It's as if each connection is tested, to determine its value. The useful circuits are kept; the others are trimmed away, leaving a sleek, efficient machine.

Premature birth likely disrupts these processes—the migration of the nerve cells, the growth of glial cells and white matter, and the trimming. Premature kids have most of the neurons they will carry with them into adult life, but it's possible they're not in the right places or properly connected or tested. Researchers, says Peterson, are "intensively testing" these possibilities.

Peterson's research offers the hope of helping children compensate for whatever brain-related peculiarities they might have. "We want to use imaging to predict who's going to have particularly difficult problems in the course of development, so we can intervene more effectively," he says. That intervention might consist of specially designed education programs or physical therapy and other treatments to compensate for physical and emotional difficulties. When Peterson began this work, his interest was professional. But now he has a personal interest as well. Two years ago, his daughter was born four weeks premature. While she shows no ill effects, he says he watches her, and he worries.

Brainstorming

When Peterson scanned me, he found nothing wrong or worrisome. If I'd had a brain tumor or some prominent abnormality, he would have spotted it. But that's about all the clinically useful information he could get from a quick scan. If Peterson had put me through the sophisticated scans he uses with the premature infants, perhaps he could have detected some quirk in the way my brain behaves. But because of the large variability in normal brain structure and function, he would not have been able to conclude much specifically about how my brain differs from those of other people.

In the coming years, however, as the technology continues to improve, it may become possible for any of us, with or without obvious illnesses or neurological problems, to learn much more about the state of our brains, our perceptions, and our thinking. "The bad news is that although these techniques are very powerful, they are not where we need to be," says MIT's Desimone. "We need to use these MRI magnets in ways they haven't been used before."

Desimone's McGovern Institute has just inaugurated the Martinos Imaging Center. One room at the center houses a state-of-the-art MRI scanner. Beside it is another room that, for the time being, will remain empty. "We have it sitting there for a new device," Desimone says. He doesn't yet know what that device will be. "That's our challenge—to invent it here. The idea is to go beyond where we are now, to the technology of the future." TR

Paul Raeburn's most recent book is Acquainted with the Night, *a memoir of raising children with depression and bipolar disorder.*

Reviews

Books, artifacts, reports, products, objects

E-MAIL

In Google We Trust

Internet users should think carefully before relying on Gmail.

By Simson Garfinkel

Google's Gmail raises important questions about the security and privacy of our personal information—questions that should matter not just to users of the free Web-based e-mail system but to everyone who exchanges e-mail with Gmail users. And since the technical underpinnings of Gmail might very well be the prototype for the next generation of desktop-computer applications, the answers to these questions potentially affect everyone.

But wait—this is not another diatribe against the targeted advertisements Gmail shows while you read your mail. All of the worry surrounding that single issue has obscured a far more important one: data integrity and security. Gmail is so powerful, fast, and convenient that there's a huge incentive for you to keep all of your e-mail there. But there's a catch: Gmail makes no promise that a mail message you save today will still be there tomorrow—nor that e-mail you delete today will be gone tomorrow. Using Gmail means placing a lot of trust in Google.

GMAIL BETA
To get an account, you must be referred by a user or sign up using a cell phone.
www.google.com/accounts/smsmailsignup1

When Gmail was launched in April 2004, it boasted three strengths: scale, search, and sales. Scale was the most obvious; Google promised each user the ability to store a gigabyte of e-mail when competitors like Hotmail were offering a measly two megabytes. Google could make this offer because, at the time, its 100,000-plus computers had more than 20 petabytes of combined storage. Since then, Google has shown it can buy new hard drives faster than its users can fill the old ones up.

Search was Gmail's second strength. Instead of asking users to create "folders" and archive their e-mail like obedient file clerks, Gmail allowed them to simply click "archive" and banish e-mail messages from their in-boxes to an unseen holding area. Gmail users retrieve their archived mail by searching for it—a process that is so fast and thorough that it's actually liberating.

Sales was Gmail's third strength—one that was surprisingly controversial. When Google announced Gmail, it proudly proclaimed that it would analyze e-mail messages for common keywords and use them to customize advertisements. For example, an undergraduate reading a message about an upcoming assignment might simultaneously see an advertisement for a site that sells term papers.

Despite this apparent convenience, many privacy activists—me among them—called upon Google to describe how its targeted-advertising technology worked. The company responded this past October by dramatically expanding and clarifying its privacy policy. Google now explains that the advertisements are based on your computer's IP address, the content of the message you're reading, and your previous use of Gmail. But don't worry, Google says: your e-mail is scanned only by computers and never by human beings.

In addition, Google now makes it clear that you can delete individual e-mail messages or your entire Gmail account at any time. If you do, however, your old e-mail might remain on Google's servers for up to 60 days and on its "offline backup systems" for even longer. Although this may sound like an unacceptably long time, Google has in fact done a far better job in addressing the concerns of privacy activists than its competitors ever did.

It's important for Google to get its privacy and security policy right with Gmail, because Gmail is the standard-bearer for an increasingly important approach to Web programming called Ajax, for asynchronous JavaScript and XML. Simply put, Ajax applications have user interfaces that run inside a Web browser, but the heavy computation and data storage are done remotely—in the case of Gmail, on Google's supercomputer cluster. When you start up Gmail, large parts of your in-box are downloaded into your computer's memory and displayed in your browser as needed. This makes Gmail dramatically faster and more efficient than existing Web-based mail systems, where messages and mailbox lists have to be downloaded again and again every time you display a new Web page.

JASON SCHNEIDER

In recent months, Gmail has introduced a message editor that lets users bold and italicize text or change fonts within a message—much the way you can in a PC-based e-mail program like Microsoft Outlook. There's even an "autosave" feature, so that if your browser crashes you don't lose the message that you were composing. And Gmail can now be integrated with Google Desktop; for example, you can download your e-mails to your Windows-based computer and search and read them when you are not online. All of this is made possible by Gmail's Ajax architecture.

So if Google is applying Ajax with such skill, why am I still concerned about privacy and security?

When most people think about privacy, they think about the threat of accidental disclosure of personal information. When they think about online security, they tend to think about worms, viruses, and phishing attacks—active attacks by bad people or bad software.

But privacy and security are more complex. Privacy, for instance, includes not just the right to keep personal matters out of the public eye but also the right to be free from intrusion—the right to be "let alone," as Samuel Warren and Louis Brandeis put it in their famous 1890 *Harvard Law Review* article "The Right to Privacy." Gmail's advertisements may be less intrusive than those of Hotmail and Yahoo, but they are intrusive nevertheless.

Google argues in its updated privacy policy that users should have the right to choose to read their e-mail through a free, advertiser-supported service. But of course, Google does not in fact offer a choice: there is no fee-based, advertising-free version of Gmail. I note this not to be obnoxious—clearly, Google can argue for choice in the market without itself having to offer more than one option—but to call attention to the most important characteristic of Google's business model.

That characteristic is this: fee-based consumer services are not part of Google's business model at all. Although Google is often called a search company or an e-mail provider, it earns its billions by selling clicks on targeted advertisements. Everything else is merely the honey designed to attract enough attention that some of it will spill onto those ads. Gmail's users are not Google's customers; they are its product. I personally find advertisements highly distasteful and have shied away from Gmail for that reason.

Far more troubling for me, however, is Gmail's data security story.

Like privacy, security is a much deeper concept than most Internet users realize. Being free from spyware and viruses is important, certainly. But so is data integrity—retaining data whole, without additions, deletions, or other modifications. While Google provides a ton of storage and great availability, there is no obvious way to back up your e-mail once it has been delivered, read, and archived. This means that you have no choice but to trust Google totally for your data integrity.

But nowhere in Gmail's "Terms of Use" does the company promise that it won't delete some or all of your mail—now, or in the future. In fact, the termination clause of Gmail's policy gives the company the right to delete any account, for any reason, at any time, with no user recourse.

Gmail could provide a backup system, of course. Google Desktop already downloads mail in the background for offline access, and it would be trivial to let users save that e-mail in archive files on their hard drives, for subsequent burning onto CD-ROMs or DVDs. Perhaps Gmail will do this in the future. But it doesn't do it now.

The mere existence of that huge archive of personal e-mail—an archive that can neither be backed up nor

deleted on demand—should give users pause. For example, such an archive could become a one-stop-shopping destination for subpoenas in civil litigation and criminal investigations. Gmail's early adopters now have nearly two years' worth of mail archived in the system—an attractive body of evidence in, say, a nasty divorce proceeding.

The preservation of old messages wasn't previously a concern because earlier online e-mail providers like Hotmail didn't offer their users enough storage. Also, folder-based archives give users a strong incentive to throw most messages away rather than keeping them all. And of course, if you download your e-mail with POP (the post office protocol) and keep it on a hard drive in your living room, you are responsible for the security of your mail—and you have the option of fighting a subpoena in court rather than turning over your files.

Many of my concerns could be addressed through the clever use of encryption. Mail could be encrypted while stored on Google's servers and only decrypted when it is displayed to Gmail users. This would dramatically reduce the risk of a subpoena: now an attorney fishing for incriminating documents would have to demand not just e-mail but also the user's decryption key. This would give users more opportunities to fight subpoenas—or perhaps to "lose" their keys.

Whether or not these risks actually matter to you depends on what uses, if any, you make of the Gmail service. But how Google responds to persistent concerns about privacy and data security should matter to everyone who uses the Web. For better or worse, Google remains the hottest Internet company on the planet—and the example it sets with Gmail will shape the products and policies of hundreds of other companies using Ajax technology to build new Web-based services. TR

Simson Garfinkel is a postgraduate fellow at Harvard University's Center for Research on Computation and Society.

COURTESY OF SPRINT

MOBILE PHONES

The Small Screen

Mobile TV is a new technology with an old business model.

By Brad King

The cell phones began arriving in the first week of September. Slowly, people began finding reasons to stop by my office. They would come in, pick up whichever phone caught their attention, look at it, ask what it did ("It streams television"), hit a few buttons, and then leave. Though mobile TV does, for the moment, suffer from technical limitations such as long buffering times and choppy streams, Sprint, Verizon, and Cingular have determined that the medium is now good enough to begin earning money for carriers. Most basic services—which offer channels such as ABC News or E!—cost roughly $10 to $15 per month, with pay-per-view clips sold for up to $4 and à la carte channels for upwards of $4 each.

And the carriers are right. Mobile TV is exciting. But for me, the daily thrill of playing around with phones that serve as teeny TVs began to fade just around the moment I crossed the threshold to my apartment after work. That's because at home, I have absolute control over what I see and how I see it. I have a Hewlett-Packard Media Center PC, a buggy but powerful machine that, in addition to serving as an ordinary computer, utterly blurs the distinction between streaming Web video and broadcast television. It allows me to watch, record, and organize video content from any source—the Web, broadcast TV, or DVDs. And because I also use the Windows Media Center Extender, I can have all that content streamed directly to my television.

Simply put, mobile television is, for the moment, the exact opposite of that experience. While Comcast may own the pipeline into my home, it doesn't control the information that goes through those pipes. With mobile

television, the only way to get content on phones is through the gatekeepers. That means that Sprint, Verizon, and Cingular can potentially dictate what you see and how you see it.

The Plot Line

In mobile TV, the main players fall into three groups: the wireless phone companies, which control the network across which all data services—voice, Web access, and text messaging—run; the major broadcast networks and cable channels, which create television content; and the companies that develop technology—both hardware and software—to enable television streaming over networks originally designed for voice traffic. The companies in this last group increasingly hope to act as aggregators who take content from broadcast partners and resell it, along with their own products, to the wireless carriers.

Much like the cable industry, where everyone must bow down before big operators such as Time Warner and Comcast, the mobile-TV industry has its kings: the wireless phone companies. In the Boston area, ESPN can't get on the television without striking a deal with Comcast, which controls the relationship with the viewer, the set-top box, and the cable lines that run into your house. Likewise, if ESPN wants sports highlights on a cell phone, it must make an agreement—either directly or through a third-party aggregator—with one of the big three mobile-television providers.

And the way the agreement works gives still more power to the wireless carriers. A broadcaster is not paid based on the number of minutes that customers spend watching its content; instead, it is paid a portion of the fee charged for whatever subscription package it is a part of. As the medium grows, mobile-TV viewers will have multiple subscription options to choose from—much as there are tiered pricing options when you sign up for cable. The mobile providers can, by power of their pipe, determine who gets easiest access to users' phones. In the world of cable, broadcasters jockey to make it into the expanded basic cable channel package, which gives them the best chance to attract the greatest number of viewers. This arrangement makes good financial sense for carriers and broadcasters, but it doesn't best serve consumers.

Still, the carriers are not operating in a vacuum; broadcasters do have some power. ABC and Fox have been among the most aggressive in developing mobile content, with the hope that they can build enough viewer loyalty to allow them to strike better deals with the mobile providers. In the cable world, companies like Disney or GE, which own many channels with large audiences, can cut cherry deals that give them high per-subscriber fees, because the cable companies know that without content that is in demand, they will lose revenue. It pays for Comcast to accommodate Disney, because Disney's ESPN brings in subscribers. Meanwhile, small networks sometimes have to pay for placement on less-frequented tiers such as the on-demand services.

MOBITV ON CINGULAR
www.mobitv.com

SPRINT TV
www.sprintpcs.com

VERIZON VCAST
www.getvcast.com

GOTV
www.1ktv.com

That's the quandary facing the third group of companies, the ones that are neither carriers nor content providers: how to claim a place on the mobile-TV network. Though each has a different business model, they all want to force a wedge between the other two groups. For some, that means building the back-end technology that allows mobile carriers to deliver television to cell phones. If a company can integrate itself into the mobile network, becoming a vital part of the delivery process, it can then give itself leverage when it comes to collecting a piece of the data-service-fee pie.

But some third-party companies want to do more than develop technology. In 2003, Sprint wanted to launch cell-phone television, but it had neither the technology nor the content. So Sprint turned to Emeryville, CA–based MobiTV, which at the time was called Idetic. The MobiTV service included a back-end architecture for delivering television to cell phones and access to a group of content partners willing to provide shows. Today, MobiTV is one of the most successful mobile-TV services, with more than 500,000 individual subscribers paying $9.99 a month to mobile carriers (which, like cable providers, then divvy up the pie and pay MobiTV a percentage) for two- to three-minute video clips and live streams from dozens of broadcasters—including Fox Sports, MSNBC, the Discovery Channel, and the Weather Channel—along with new services such as Mobi-MLB, which offers live audio broadcasts of every major-league baseball game.

The problem for MobiTV is that it could easily be swept aside by San Diego's Qualcomm, one of the largest makers of communication chips for cell phones. Qualcomm is currently developing both a proprietary system to deliver video to mobile phones and its own subsidiary content-aggregating service.

But as the heavyweights try to corner the mobile-TV market by simply repurposing highlights from news, entertainment, and sports programming, the best hope for innovative content may lie with companies like Sherman Oaks, CA's GoTV. GoTV's original programming, created with the smaller screen size of the mobile phone in mind, could be to mobile TV what the music video was to cable television in the 1980s: content perfectly tailored to the new medium. Whether it will be the small companies or the big companies that produce the most-popular mobile-TV content remains to be seen. What's certain is that all content providers will spend a lot of their time seeking audiences with the carriers. TR

Brad King is Technology Review*'s Web producer and senior editor.*

NATIONAL SECURITY

A Tangle of Wires

Could Washington's approach to cybersecurity be worse? Possibly, if it had an approach.

By Bryant Urstadt

Cybersecurity? What cybersecurity? Citizens who may have harbored the idea that there was a murderously efficient J. Edgar Hoover of the Internet, working day and night, will be much disappointed at the contents of two recent government reports. They are easy to summarize: not only is very little of use being done, but essentially nobody is doing it. There is barely a boss and hardly any techno-G-men defending us from hackers, terrorists, scam artists, foreign nations, and others who might wish to do our Internet harm. The major problems in Internet security [many of which are detailed in "The Internet Is Broken" on page 62], are nowhere close to being addressed at the federal level, and what little is being done is on the wrong track, favoring summits, partnerships, and "information sharing" over the much more necessary but less visible work of long-term research and development.

CRITICAL INFRASTRUCTURE PROTECTION: DEPARTMENT OF HOMELAND SECURITY FACES CHALLENGES IN FULFILLING CYBERSECURITY RESPONSIBILITIES
U. S. Government Accountability Office
May 2005
www.gao.gov/new.items/d05434.pdf

CYBER SECURITY: A CRISIS OF PRIORITIZATION
The President's Information Technology Advisory Committee
February 2005
www.nitrd.gov/pitac/reports/

These charges seem less outrageous considering the state of the position of assistant secretary for cybersecurity and telecommunications, in the U.S. Department of Homeland Security. This is the office nominally charged with coördinating and overseeing our government's efforts to secure cyberspace, which have run into a slight problem: there is no assistant secretary of cybersecurity and telecommunications. And there hasn't been since July 2005, when secretary of homeland security Michael Chertoff announced the creation of the position as part of a reorganization. The position it succeeded had been the product of a reorganization, too. There *is* an acting director of the old department, the National Cyber Security Division, but his office will be bumped down a level upon the appointment of the assistant secretary.

That's business as usual at the DHS, where, in the last four years, three appointees, all solid industry veterans, have reported to head up the various incarnations of the cybersecurity department but packed it in after about a year. One seems to have left out of frustration—the position, whatever it has been called, holds little power but all accountability for anything that might go wrong—and others have seen their department evaporate from beneath them.

All of this is detailed in "Critical Infrastructure Protection: Department of Homeland Security Faces Challenges in Fulfilling Cybersecurity Responsibilities," a report presented by the U.S. Government Accountability Office to Congress in May 2005. By the standards of a document written in governmentese, it's withering. It contends that "While DHS has initiated multiple efforts, it has not fully addressed any of the 13 key cybersecurity-related responsibilities that we identified…and it has much work ahead in order to be able to fully address them."

The GAO, in its criticisms, starts with the basics. The DHS has no plan. It has an interim plan, the Interim National Infrastructure Protection Plan, but that "does not yet comprise a comprehensive and complete plan." It is missing, for one thing, details on "addressing cybersecurity in the infrastructure sectors." This means there is no plan to defend the financial industry and water and electric utilities from attacks. That's a serious lack of plan.

The network police also seem to have their own trouble networking. One of the DHS cyber division's main responsibilities is "information sharing," among agencies and with state and local government and businesses. Relations with some of these are "disintegrating." The cyber division has had limited authority to move classified information around, and the private sector, unsure who's at the bridge, has been slow to share secrets of its own.

Nor is DHS developing the analytic tools needed for an effective defense system. Like the rest of us, the agency can tell when an attack is well under way—hey, my computer keeps shutting down!—but it has failed to produce a reliable early-warning system. The report notes that the GAO made this same complaint four years ago but that "officials have taken little action."

The GAO also notes a real lack of recovery planning, including a shortage of preparatory exercises. Nor has the DHS done enough to assess the problems it faces, as is called for in policy documents. Failing to assess vulnerabilities will lead to difficulties in deciding which resources to allot to which sector. DHS, in short, isn't even sure what threats we face. The report also notes a lack of guidance from the cybersecurity department in setting goals for long-term research and the "unclear" effectiveness of awareness efforts—both those directed toward the public and those directed toward other agencies and government entities.

Not surprisingly, the GAO places the blame for all of this inactivity on the deleterious effects of the revolving door in the head office and the consequent lack of stability and authority within the division. With such volatility, the report


BROOKS KRAFT/CORBIS

Richard Clarke resigned as head cybercop in 2003. After him, more followed suit.

states, it's been almost impossible to hire the best people, "key contractors" have had to work without pay, and vendors have even gone unpaid.

The second report, "Cyber Security: A Crisis of Prioritization," was prepared by the President's Information Technology Advisory Committee (PITAC) and delivered to the executive branch in February 2005. It's equally pessimistic but, on the bright side, does in its way offer a solution to the long-term problem of cybersecurity. Whether it will be heeded is another matter. Where the GAO limited itself to assessing how the DHS was doing by the relatively narrow standards of the DHS's own mission statements and policy, PITAC provides more thoughtful criticism of and advice about the approach of the entire government, focusing on the kinds of research that will ultimately solve our network security problems.

PITAC was a group comprising about equal numbers of academics and representatives of the technology industry, and the Cyber Security Subcommittee, which prepared the report, was chaired by Tom Leighton, MIT prof and Akamai cofounder. Originally appointed by Clinton, the gang was reupped by Bush early in his first term. After it delivered its report, its contract was not renewed. This is not surprising, as it had few encouraging words about the government's current approach.

The executive branch specifically asked for comments on the state of research and development in Internet security, and PITAC responded with certainty that "the Federal government needs to fundamentally improve its approach to cyber security." The current security problem, the report argues, derives from a "decades-long failure to develop the security protocols and practices…and to adequately train and grow the numbers of experts needed to employ these mechanisms effectively."

Research and development funds, the report argues, are increasingly being funneled toward defense-related technology with short-term objectives. Worse, that technology is kept classified, a serious obstacle considering that the majority of the Internet's infrastructure is in private hands. Nor is the private market picking up the slack, focusing instead on "the application of existing technologies to develop marketable products." This, the report points out, is in sad contrast to the larger federal research budgets of old, and the relatively open halls of the Advanced Research Projects Agency in the Department of Defense, which in retrospect comes off as something like Rafael's *School of Athens*, and which gave us the Internet in the first place. The National Security Agency *is* funding such open research through its Information Assurance group, but only 20 percent of that money is headed toward fundamental research, and only $3 million of that toward academic research. In the world of Washington, that's nothing.

The majority of federal funding for open civilian research is doled out through the National Science Foundation, DHS, the National Institute of Standards and Technology, and the Department of Justice, but the NSF grants the lion's share of these funds. DHS is barely supporting long-term research, with a mere $1.5 million of its $1 billion science and technology budget. The report recommends an increase of $90 million in the NSF budget alone, noting that merely 8 percent of NSF grant applications for cybersecurity research were filled, or one-third of the agency's average across disciplines.

As for personnel, the report claims that at U.S. academic institutions today, "there are fewer than 250 active cyber security or cyber assurance specialists," largely due to "insufficient" and "unstable" funding. PITAC would like to see the size of the research community at least doubled. Lastly, the report points out that "the government-wide coördination of cyber security R&D is ineffective," with agencies focusing on "their individual missions" and losing sight of "overarching national needs."

So here we have two major problems: an open position in a dysfunctional department and a serious lack of long-term research. With that in mind, is it too much to hope for a different kind of candidate for the job of assistant secretary than the last few we have seen? Instead of looking for an old Beltway hand or an exec from the IT business, perhaps the administration ought to look for the kind of person who can't wait to spend a few hours pondering the possibilities of self-aware and self-healing systems. Such a figure might be less useful in overseeing the myriad of talks that go on between agencies at home and abroad, but the handshakes so far haven't produced much, and given the vulnerabilities of the Internet in its current design, they seem unlikely to pay off with anything more than a very full calendar of seminars and announcements. DHS needs a visionary. TR

Bryant Urstadt has written for Harper's, Rolling Stone, *and the* New Yorker.

Demo

Sensing Success

MIT's Scott Manalis shows off his ultrasensitive biomolecule detector.

By David Rotman

Scott Manalis holds in his palm a thin microchip about the size of a fingernail. To the naked eye, it looks similar to the chips you might find in your cell phone or iPod. What's different is buried in the chip and hidden from sight: a suspended vibrating microchannel carved out of silicon. It is, says Manalis, "to our knowledge, the world's most sensitive way to measure the mass of biomolecules or the mass of cells in an aqueous environment."

Pointing to a micrograph showing a cross section of the chip, Manalis, who developed the sensor with then graduate student Thomas Burg, explains how the technology works. The key is the microchannel, which is 300 micrometers long, 50 micrometers wide, and a few micrometers thick. It acts like a tiny diving board; once its inner surface is chemically treated, specific proteins or other biomolecules selectively bind to it, and the added weight changes the frequency of its vibrations. That change, which can be measured either electronically or with a laser, corresponds directly with the mass of the binding molecules.

Manalis, a professor of biological and mechanical engineering at MIT's Media Lab, believes the technology could provide not only an extremely sensitive but also a highly practical method for detecting everything from viruses to cells to protein biomarkers. Indeed, this fall Manalis received a five-year, $3.2 million grant from the National Cancer Institute to develop a sensor for sniffing out the rare proteins that can be the telltale signs of cancer. His first target: prostate cancer.

With standard techniques, detecting biomolecules generally requires labeling them with fluorescent tags. The glow of the tags can be measured with an optical reader to determine whether a particular molecule is present and, if so, in what quantities. This technology has become one of the workhorse tools of biotechnology and is used, for example, in DNA microarrays for genetic testing. But fluorescence-based devices have two severe limitations: first, because they require chemical labels and precise optical equipment, they are often inconvenient to use and fragile; and second, they can't easily be shrunk and integrated into a microchip.

Manalis says his method for the direct detection of biomolecules does not suffer those drawbacks. Because it doesn't use fluorescence, it doesn't use an optical reader. That, says Manalis, makes it "much more robust. You can drop it." And because its manufacture relies on the same basic process as any other silicon microchip's, the detector can be easily miniaturized and combined with other silicon components. A series of tiny, nearly identical microchannels could be fabricated alongside each other, yielding a device capable of rapidly measuring many different types of samples.

A Liquid Asset

The ease of integrating the silicon detector with other components should make it useful in microfluidics, a hot

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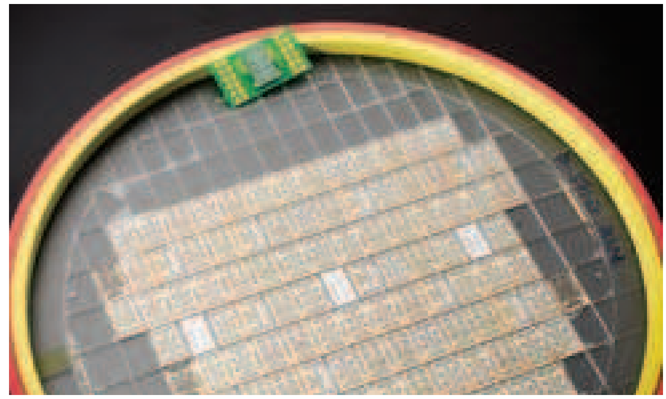
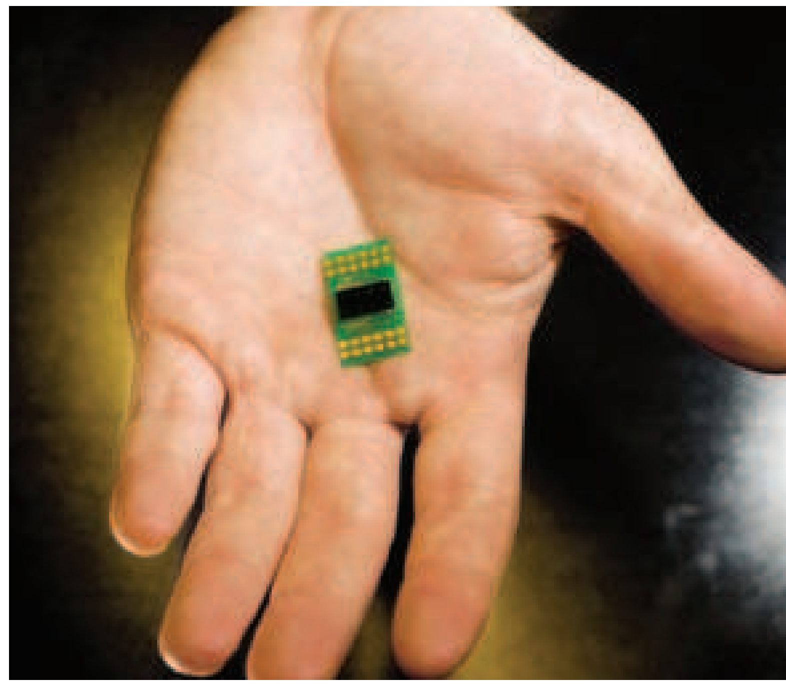
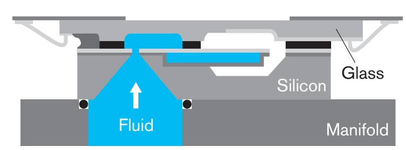




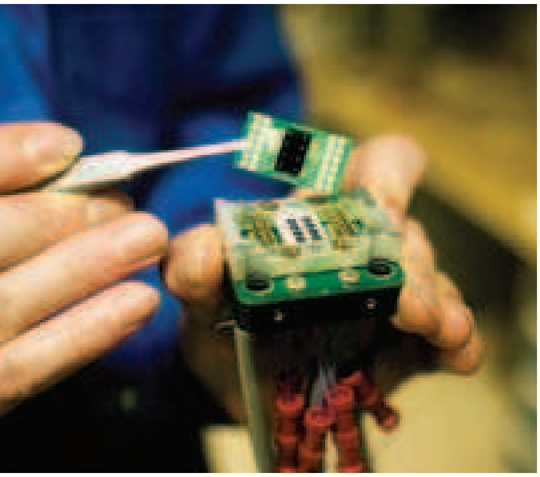
area of biomedical research. In microfluidics, the various steps involved in preparing and testing a sample are executed on a microchip. The liquid in, say, a blood sample moves through microscopic channels, where procedures such as bursting open cells, separating their component molecules, and running tests on those molecules all happen in tiny channels. Manalis says the silicon microchannels built by his lab can be easily incorporated into such a microfluidic scheme. His detectors, he points out, determine the contents of an extremely small volume of liquid, about 10 picoliters—roughly the volume of a single cell.

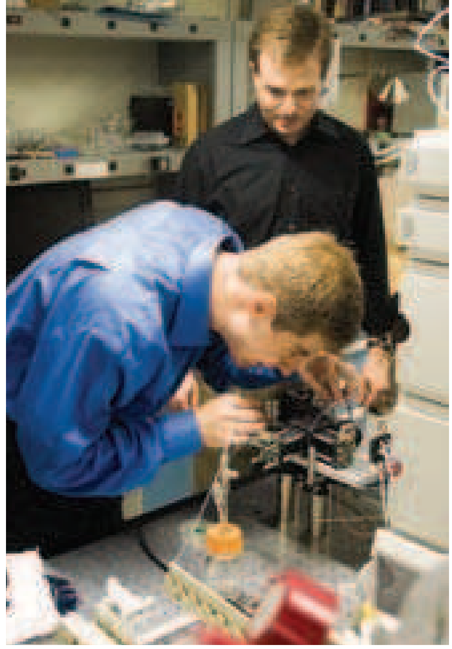
Other physicists have shown that microscopic vibrating cantilevers could be an extremely sensitive method for detecting mass, explains Manalis. "If you talk to physicists, their favorite quantity to measure is vibrational frequency because it is very easy to measure. It's very robust, and it is very hard to interfere with." But previous work had encountered a seemingly insurmountable practical problem when it came to detecting biomolecules: the cantilevers had to operate in a dry environment, preferably in a vacuum. In water or any other liquid, the delicate vibrations would be instantly damped. That's a problem, says Manalis, because the biomolecules that scientists want to detect—viruses, for example—are found in aqueous environments, such as a blood sample.

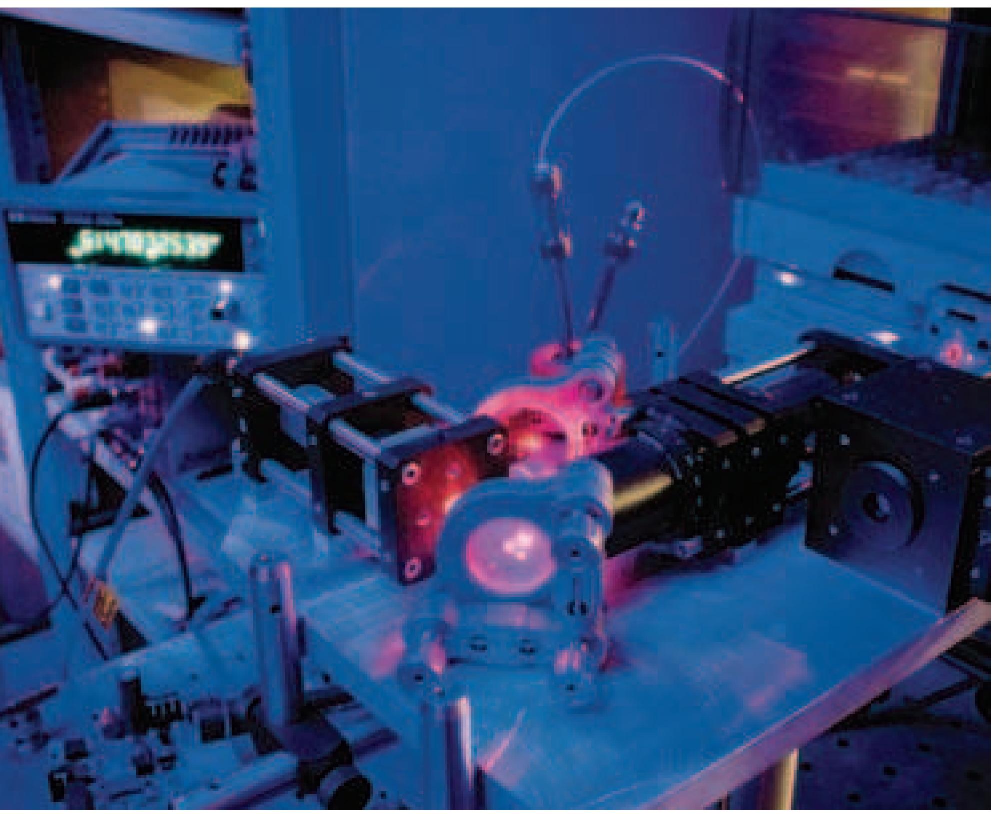


CHIP IN HAND

The MIT Media Lab's Scott Manalis *(far left)* has headed the effort to develop a tiny, ultrasensitive detector for biomolecules. One advantage of the new silicon sensors is that they can be microfabricated in a process similar to the one used for conventional semiconductor technology *(top)*. The result is a familiar-looking chip; the tiny vibrating microchannels are, literally, within a black box at the center of the chip *(above)*. A schematic shows the inner workings of an early version of the chip. The fluid sample flows into the hollow suspended microchannel, which is elecrostatically resonated; biomolecules in the sample change the frequency of the vibrations.







COUNTING ON IT

Postdoc Thomas Burg, who developed the biomolecule detector chip as part of his doctoral thesis, is busy these days optimizing its performance. As it undergoes the countless experiments required to verify its accuracy, the chip is mounted securely *(left)*. While the vibrations of the suspended microchannel at the heart of the chip will eventually be measured electronically, for now Burg uses an external laser; the changes in vibrational frequency are displayed on a digital counter *(bottom).* The researchers have demonstrated they can measure resonator frequency with accuracy of one part in a million.

In biology, he points out, "everything happens wet."

It is here that Manalis came up with an ingenious solution. He and his colleagues hollowed out a tiny channel inside the cantilever so that small volumes of the sample would flow into it; the targeted biomolecules bind to the inner walls. The vibrations of the suspended resonator are still affected by the mass of the binding molecules, but there is no longer any surrounding fluid to damp them.

Of course, it's one thing to design such a device; it's quite another to get it working reliably at the limits of its sensitivity. Burg, now a postdoc, developed the device for his doctoral thesis and has solved many of the problems of how the tiny suspended microchannel interacts with the outside world.

Manalis and Burg hope one day to build the detector into a small handheld device that could be used to detect pathogenic viruses or for a quick and easy cancer test in a doctor's office. But for now, the chip that Burg is testing is hooked up to a tangle of electrical wires and held tightly by several small clamps at the end of a lab bench. A laser is aimed at the chip to measure precisely the vibrational frequency of the suspended microchannels. Plastic tubes protrude from holes dotting the chip and run to an automated liquid-handling instrument.

For physicists like Manalis and Burg, who are used to working with precise semiconductor technology, optimizing the chemistry and the flow of the liquids is the trickiest part of the experiments. The researchers first treat the inner walls of the microchannel with specific antibodies that will selectively bind to the target biomolecules, such as a particular type of protein. The chemistry is not novel, says Burg, but because it's affected by temperature and other factors, it's unpredictable. For that reason, the group gathers seemingly endless data (the automated experiment runs through the night) to ensure that the microchannel is accurately and consistently detecting the targeted biomolecules.

If all goes well, though, within the next year the experimental device could move from all-nighters in the MIT lab to testing out in the real world. At that point, Innovative Micro Technology, a foundry in Santa Barbara, CA, will take over the production of standardized versions of the highly sensitive detectors. TR

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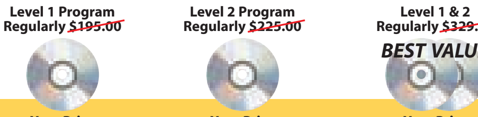

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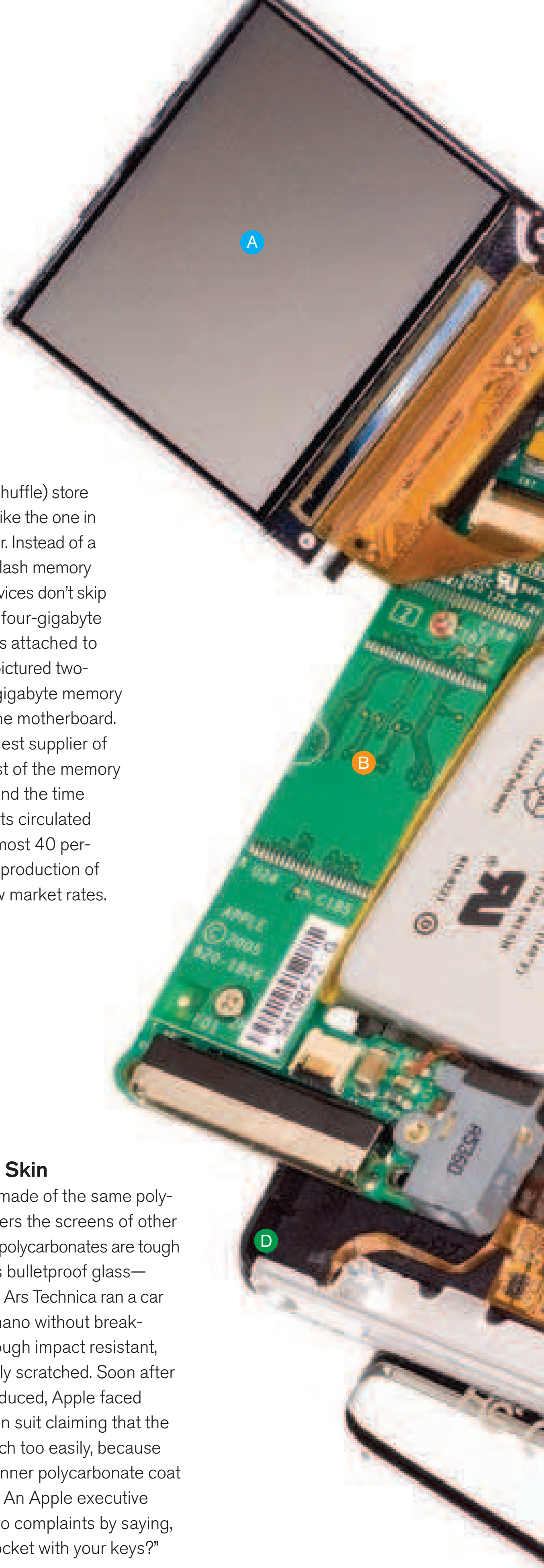
Hack

The iPod Nano

We voided the warranty so you don't have to. Here's a look inside Apple's flashy new toy.

By Daniel Turner



CHRISTOPHER HARTING

A Liquid-Crystal Display

Analysts who have broken down the costs of the nano's parts say that the liquid-crystal display accounts for almost 8.5 percent of the total. The 1.5-inch screen is the first color screen in any iPod other than the full-size version. In addition, the screen offers functionality—displaying homemade photo galleries and album art—that not so long ago was available only in the iPod Photo, which cost $500 for a 40-gigabyte version. You can even use the nano to store and carry around your PowerPoint presentations. This might make it a deductible business expense.

B Flash Drive

Other iPods (besides the shuffle) store music on a hard drive just like the one in your computer, only smaller. Instead of a hard drive, the nano uses flash memory chips; these solid-state devices don't skip and use less power. In the four-gigabyte model, the flash memory is attached to a daughterboard; in the pictured two-gigabyte model, two one-gigabyte memory chips are soldered onto the motherboard. Samsung, the world's largest supplier of flash memory, makes most of the memory chips used in nanos. Around the time of the nano's debut, reports circulated that Apple had bought almost 40 percent of Samsung's entire production of such chips, possibly below market rates.

C Battery

Like all iPods, the nano has a rechargeable lithium-ion polymer battery. The battery's polymer electrolyte allows designers to mold the battery like modeling clay and also obviates the need for the organic solvent used in previous designs. This is a particular advantage for a product designed to go into a pants pocket, as the solvent had the bad habit of occasionally igniting. Like most lithium polymer batteries, this one uses a fast-charge system that restores 80 percent of its 14-hour charge in about an hour and a half; the remaining 20 percent takes another hour and a half. Still, even this battery will eventually die after a few years. The fact that no iPod is designed to allow the user to replace the battery led to a customer class action suit that Apple settled in June 2005. But even though pulling your iPod to pieces, as we've done here, voids the warranty, many third parties have offered longer-life replacement batteries for previous iPod models (with replacement instructions) and may do so for the nano.

D Polycarbonate Skin

The nano's skin is made of the same polycarbonate that covers the screens of other iPod models. Many polycarbonates are tough enough to serve as bulletproof glass—indeed, the website Ars Technica ran a car repeatedly over a nano without breaking its skin. But though impact resistant, the material is easily scratched. Soon after the nano was introduced, Apple faced another class action suit claiming that the iPod scratches much too easily, because its screen has a thinner polycarbonate coat than other models'. An Apple executive reportedly replied to complaints by saying, "You keep it in a pocket with your keys?"

E Cache Memory

In hard drive–based iPods, cache memory plays the crucial role of continually storing blocks of music decoded from the hard drive. If the hard drive, like a vinyl record, skips from being knocked around, as can happen at the gym, the cache can stream music without interruption. The flash drive in the nano is solid state instead of mechanical like a hard drive, so there's no way it can skip. As a result, the four megabytes of Samsung dynamic random-access memory aren't used so much for caching as for general memory for the nano's main processor and operating system, just as in a regular computer. This means there's more memory available to let the system handle images and long lists of songs, or to reduce the number of times the processor has to fetch data from the flash memory, which saves power and extends battery life.

F Portal Player Chip

You've stored a thousand songs on your nano, but that's as *1*s and *0*s. The processor—the same type that powers the full-size iPod—is hard-wired to translate data taken from the flash drive into analog sounds, amplifying them before they reach your headphones. Just like the large and power-hungry CPU in your desktop PC, the processor also manages files, the user interface, and digital-rights management software for the music you've purchased from Apple's iTunes Music Store.

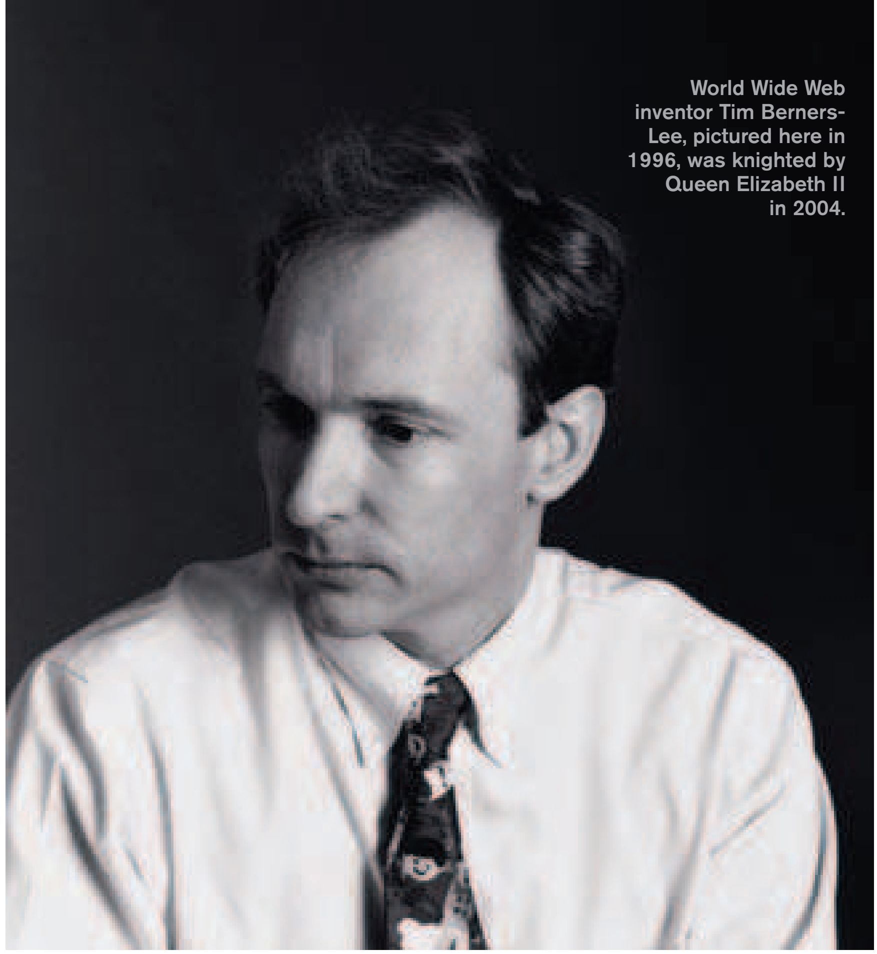
G Click-Wheel Controller Chip

From the start, the iPod's signature feature was its wheel controller. Though the click wheel doesn't register how hard you click, it does respond to how you touch it: the farther you scroll, the faster you scroll. This makes it easy to move through a list of ten thousand songs. Apple touted this feature when the first iPod came out in 2001, with a wheel that physically rotated. Its successor, the first touch-sensitive wheel for the iPod, was built by Synaptics; to develop the nano's click wheel and controller, however, Apple contracted Cypress Semiconductor. No parties are talking about why the switch was made, but perhaps a clue to (or merely a result of) the decision is the fact that Creative Technology's Zen Touch MP3 player uses a Synaptics touch pad.

10 Years Ago in *TR*

Click "Oh yeah?"

How the Web's inventor viewed security issues a decade ago.



World Wide Web inventor Tim Berners-Lee, pictured here in 1996, was knighted by Queen Elizabeth II in 2004.

HENRY HORENSTEIN/CORBIS

As part of a larger proposed effort to rethink the Internet's architecture *(see "The Internet Is Broken," p. 62)*, Internet elders such as MIT's David D. Clark argue that authentication—verification of the identity of a person or organization you are communicating with—should be part of the basic architecture of a new Internet. Authentication technologies could, for example, make it possible to determine if an e-mail asking for account information was really from your bank, and not from a scam artist trying to steal your money.

Back in 1996, as the popularity of the World Wide Web was burgeoning, Tim Berners-Lee, the Web's inventor, was already thinking about authentication. In an article published in July of that year, *Technology Review* spoke with him about his creation. The talk was wide ranging; Berners-Lee described having to convince people to put information on the Web in its early years and expressed surprise at people's tolerance for typing code. But he also addressed complaints about the Web's reliability and safety. He proposed a simple authentication tool—a browser button labeled "Oh, yeah?" that would verify identities—and suggested that Web surfers take responsibility for avoiding junk information online. Two responses are excerpted here. KATHERINE BOURZAC

From Technology Review, *July 1996:*

TR: The Web has a reputation in some quarters as more sizzle than steak—you hear people complain that there's no way of judging the authenticity or reliability of the information they find there. What would you do about this?

Berners-Lee: People will have to learn who they can trust on the Web. One way to do this is to put what I call an "Oh, yeah?" button on the browser. Say you're going into uncharted territory on the Web and you find some piece of information that is critical to the decision you're going to make, but you're not confident that the source of the information is who it is claimed to be. You should be able to click on "Oh, yeah?" and the browser program would tell the server computer to get some authentication—by comparing encrypted digital signatures, for example—that the document was in fact generated by its claimed author. The server could then present you with an argument as to why you might believe this document or why you might not.

...Another common gripe is that the Web is drowning in banal and useless material. After a while, some people get fed up and stop bothering with it.

To people who complain that they have been reading junk, I suggest they think about how they got there. A link implies things about quality. A link from a quality source will generally be only to other quality documents. A link to a low-quality document reduces the effective quality of the source document. The lesson for people who create Web documents is that the links are just as important as the other content because that is how you give quality to the people who read your article. That's how paper publications establish their credibility—they get their information from credible sources....You don't go down the street, after all, picking up every piece of paper blowing in the breeze. If you find that a search engine gives you garbage, don't use it. TR

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